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“EFFECT OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES IN GMAW”

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CANDIDATE'S DECLARATION

I, MANU RAJ, hereby certify that the work which is being presented in the thesis entitled **"EFFECT OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES IN GMAW"** in the partial fulfilment of requirement for the award of degree of MASTER OF ENGINEERING submitted in the Department of Mechanical Engineering at DELHI TECHNOLOGICAL UNIVERSITY, DELHI, is an authentic record of my own work carried out under the supervision of **Dr. (Mrs.) Reeta Wattal,** Professor, Department of Mechanical engineering. The matter presented in this thesis has not been submitted in any other University / Institute for the award of any degree. This thesis does not contain any plagiarized content. All the references undertaken are mentioned at the end of the thesis.

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CERTIFICATE

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This is to certify that the report entitled **““EFFECT OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES IN GMAW”** submitted by MANU RAJ (roll no. 2K11/PIE/09) is the requirement of the partial fulfilment for the award of Degree of Masters of Technology in Production Engineering at Delhi Technological University. This work was completed under my supervision and guidance.

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ABSTRACT

This experimental study was carried out to analyse the effects of process parameters on mechanical properties in Gas metal arc welded mild steel. GMAW process is one of the most efficient process for welding metals like Aluminum, low carbon steels, stainless steels etc which find great use in industries. Due to its versatility it has always been the centre of focus for researchers and industrialists. There are many process parameters which affect mechanical properties and bead geometry such as welding current(wire feed rate), polarity, arc voltage ,travel speed electrode extension shielding gas etc. Out of these wire feed rate arc voltage and speed were chosen for studying their effect on mechanical properties such as ultimate tensile strength, yield strength, percent elongation ,notch tensile strength and impact strength. It was found that with increase in arc voltage and wire feed rate tensile and impact properties decreases while when speed increases the tensile and impact properties also increases. It was also observed that ultimate notch tensile strength of welded metal was found greater than their corresponding ultimate tensile strength clearly stating that the specimens belong to notch ductile category. It was also found that the notch strength ratio of the base metal was more than all the welded specimen.

Full factorial technique was used to formulate the experimental layout and to analyse the effects of process parameters on the mechanical properties of mild steel. Regression technique was used to formulate mathematical model .The models developed have been checked for their adequacy and significance by using ANOVA technique and t-test. Main and interaction effects of the process variables on responses are presented in graphical form.

Keywords:- Gas Metal Arc Welding (GMAW), mild steel, Full factorial technique.

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LIST OF ABBREVIATION

Symbols/Notations used throughout the text of this thesis are explained as given below in alphabetical order.

1. CTWD..Contact tip to work distance
2. DCEP..Direct current electrode positive
3. GMAW...Gas metal arc welding
4. I..Impact strength
5. N.T.S...Notch tensile strength(ultimate)
6. S...welding speed
7. UTS...ultimate tensile strength
8. V...Arc voltage
9. W..Wire feed rate
10. Y.S..Yield strength
11. %E..Percent elongation

CHAPTER -1

INTRODUCTION

1.1 Introduction

In order to fabricate structures and machine parts welding is required . GMAW, was first used in the USA in the mid 1940s. Since those early days the process has found extensive use in a wide range of industries from automotive manufacture to cross-country pipelines. It is an arc welding process that uses a continuously fed wire both as electrode and as filler metal, the arc and the weld pool being protected by an inert gas shield. It offers the advantages of high welding speeds, smaller heat affected zones than TIG welding, excellent oxide film removal during welding and an all positional welding capability. For these reasons MIG welding is the most widely used manual arc welding process for the joining of aluminium, later it was used to weld almost all the metals except a few. Mild steel is one of the most easiest weldable material in this project work has been done on mild steel.

Mild steel consists of iron alloyed with less than 0.3 percent carbon, most commonly between 0.1 to 0.25 percent. The building industry frequently uses mild steel in construction because of its ductility and malleability. Mild steel is a type of steel that contains only a small amount of carbon and other elements. It is softer and can be shaped more easily than higher carbon steels. It also bends a long way instead of breaking because it is ductile. It is used in nails and some types of wire, it can be used to make bottle openers, chairs, staplers, staples, railings and most common metal products. Its name comes from the fact it only has less carbon than steel. The brackets that hold up a shelf are made from mild steel. The chassis and body panels of most cars are mild steel.

There is literally millions of uses for it. It can be cut, drilled, machined, threaded or tapped, rolled, formed, bent, welded, forged in a mould, folded (to form a weapon or tool), pressed, stamped, spun into wire or cable, magnetised and the list goes on. So it has always been centre of focus for the researchers to understand the mechanical properties of mild steel after welding as most of body parts of cars are attached to chassis which is of mild steel. Not only in automobile industry but also in construction and power plant industry mild steel finds a great usage.

1.2 Motivation and Objective:-

The motivation was provided by the desire to explore the frontiers of welding technology, which forms the backbone of manufacturing industries. Several researchers have attempted to investigate the effects of various process parameters on responses in GMAW

The objective of this project was to study the GMAW process in its totality and to explore the potential of controlling the process so as to get desired outputs by simply manipulating the input process variables. To be able to successfully use a process in industry it is imperative that we have a robust way of controlling the outputs as per our needs. The main objective of this project was to understand the influence of process variables such as Arc Voltage, wire feed rate and Travel Speed on the mechanical properties such as ultimate tensile strength, impact strength, notch tensile strength etc and to quantify the relationships through development of mathematical models co-relating the two. Further these models were analysed by ANOVA and significance is tested by t test.

1.3 Statement of problem

"Effect of process parameters on mechanical properties in GMAW".

The project describes the effects of arc voltage wire feed rate and speed of weld on tensile strength, notch tensile strength, impact strength , yield strength and % elongation of GMAW welded mild steel. Mathematical models were developed for predicting tensile strength, notch tensile strength, impact strength , yield strength and % elongation using full factorial technique.

1.4 Plan of Investigation

The research work was planned to be carried out in following steps:

1. Identification of important process control variables.

2. Deciding the working range of the process control variables, viz. Arc Voltage (V), wire feed rate(W), & Travel Speed (S).
3. Developing the design matrix.
4. Conducting the experiments as per the design matrix.
5. Recording the responses viz. tensile strength, notch tensile strength, impact strength yield strength and % elongation.
6. Developing the mathematical models.
7. Checking the adequacy of the models.
8. Finding the significance of co-efficient.
9. Developing the final proposed models.
10. Plotting of graphs and drawing conclusions.
11. Discussion of the results.

CHAPTER-2

LITERATURE REVIEW

2.1introduction

Welding is a fabrication process that joins two metals or non-metals by producing coalescence between them. This is generally achieved by heating the specimen up to their melting temperature with or without the addition of filler materials, to form a pool of molten metal that cool and solidifies to become a strong joints.

The mechanical properties of the weld joint has always been the centre of attraction for researchers and scholars. A lot of work has been done in this field to test the effect of process parameters such as welding current, voltage, nozzle to plate distance, welding speed, welding angle and gas flow rate on hardness, tensile, fatigue and impact strength. The following literature reviews makes an attempt to provide an insight in to the above mentioned area.

2.2 Literature Review

A.K.Lakshminarayan et al[1] analysed the effect of autogenous arc welding process on tensile and impact properties of ferritic stainless steel. Out of the three welding techniques used i.e constant current tungsten arc welding(CCGTAW), pulsed current gas tungsten gas arc welding(PCGTAW) and plasma arc welding(PAW) ,the joints fabricated by PAW exhibit higher tensile strength ,impact strength and high fusion zone hardness. Of the three welded joints. the joints fabricated by PAW exhibited higher impact toughness values and the enhancement in impact toughness was approximately 25% when compared with CCGTAW joints, and 50% when compared with PCGTAW joints.

Hardeep Singh et al[2] analysed the effect of tensile strength in electric arc process and optimized the effects of welding current and time on tensile strength. They concluded that Time is the most significant factor than current for Tensile Strength response .It is interesting to note that Tensile Strength displaying an increasing trend with an increase in time & current parameters. For maximum Tensile Strength current is to set at max. Level .

Izzatul Aini Ibrahim et al[3] studied the Effect of Gas Metal Arc Welding (GMAW) processes on different welding parameters. In this study, the effects of different parameters on welding penetration, microstructural and hardness measurement in mild steel that having the 6mm thickness of base metal by using the robotic gas metal arc welding are investigated. The variables that choose in this study are arc voltage, welding current and welding speed. The value of depth of penetration increased by increasing the value of welding current 90, 150 and 210 A. Welding current is factor that will determine the penetration. Penetration also influence by the factors from welding speed and arc voltage. At the welding speed 60cm/min, the good value for penetration happened is 26 V at 210 A.

Mitsuhiro Okayasu et al[4] studied mechanical properties of SPCC low carbon steel joints prepared by metal inert gas welding To better understand the fatigue and tensile properties of SPCC steels welded by metal inert gas welding, the mechanical properties of the welded component in several localized regions, e.g., weld metal, heat affected zone (HAZ) and base metal, were investigated. The tensile and fatigue properties of the weld metals were high compared to the other areas (base metal and HAZ) due to the precipitated Ti containing oxide inclusions in acicular ferrite (bainite). The mechanical properties of the weld sample were further investigated using test specimens that included all regions, i.e., weld metal, HAZ and base metal (BHW). The tensile and fatigue properties of the BHW sample were found to be lower than those in all other regions, which was influenced by the high internal stress. The mechanical properties were analyzed using microstructural and crystal characteristics, as examined by TEM and EBSD analysis.

Durgutlu et al[5] In this study, the effect of hydrogen in argon as shielding gas was investigated for tungsten inert gas welding of 316L austenitic stainless steel.The microstructure, penetration and mechanical properties were examined. Pure argon, 1.5% H2–Ar and 5% H2–Ar were used as shielding gas. On the basis of the mechanical properties and microstructural experimental studies accomplished and the results obtained on the effect of hydrogen in the shielding gas on the TIG welding processes of 316L austenitic stainless steel the following conclusions may be drawn that For tensile strength, the best result is obtained from 1.5%H2–Ar as gas shielding. Cracks, tearing and surface defection were not with naked eye observed after bending the samples welded under all three shielding media. For all shielding media, hardness of weld metal is lower than that of the HAZ and base metal. Penetration profile examinations for all three different shielding gases show that penetration depth and weld bead width increases with increasing hydrogen content.

S.K.Nath et al[6] from iitr studied Fracture toughness of medium carbon steel (0.5% C) has been determined by round notched tensile specimen. Two notch diameters (5.6mm and 4.2mm) and three notch angles (α) namely 450, 600 and 750 have been used to observe the effect of notch diameters and notch angle on fracture toughness of the steel. By heat treatment the microstructure of the steel is also varied and its effect on the fracture toughness is also observed. It has been found that fine grained structure improves fracture toughness. Lower notch diameter and higher notch angle show higher value of K1C.

N.Arivazghan et al[7] This paper reports the work carried out on welding of AISI 304 and Monel 400 using Gas Tungsten Arc Welding (GTAW) technique to examine the weldability, mechanical and metallurgical properties. Investigations have been carried out on the hot corrosion behavior of these joints subjected to cyclic air oxidation and K2SO4 + NaCl (60%) molten salt environment at 600C. A comparative analysis was carried out on these weldments for two different filler metals such as E309L and ENiCu-7. The oxide scales formed on the various zones of the weldment have been characterized systematically using surface analytical techniques. Weld zone was found to be more susceptible to degradation than base metals used. The effect of filler materials on the hot corrosion is discussed. The studies reported in this paper would be beneficial for fabricators embracing this type of dissimilar weldments in the petrochemical and power generation industries.

J.P.Ganjigati et al[8] In this paper, an attempt is made to establish input–output relationships in MIG welding process through regression analyses carried out both globally (i.e., one set of response equations for the entire range of the variables) as well as cluster-wise. It is important to mention that the second approach makes use of the entropy-based fuzzy clusters. The investigation is based on the data collected through full-factorial design of experiments. Results of the above two approaches are compared and some concluding remarks are made. The cluster-wise regression analysis is found to perform a slightly better than the global approach in predicting weld bead-geometric parameters.

D.W.Chao et al [9] This study performed three-dimensional transient numerical simulations using the volume of fluid method in a gas metal arc V-groove welding process with and without root gap for flat, overhead, and vertical welding positions. The elliptically symmetric arc models for arc heat flux, electromagnetic force and arc pressure were used to describe the more accurate molten pool behaviours. The numerical models not only formed a stable weld bead but also simulated the dynamic molten pool behaviours such as overflow which was not described before. This study analyzed these molten pool flow patterns for various welding positions and validated the numerical models used by comparing the simulation results with experimental ones.

Remus Boboescu et al[10] Laser welding using Nd: YAG laser with continuous emission is applied for a low alloyed steel. The study pursued molten areas characteristics in the material. On the weld cross section was measured weld width, weld depth and the weld molten zone. Their variation was analyzed with power and welding speed. A full factorial experimental design was applied for two particular values of the distance between focal plane and the workpiece surface (defocusing depth). It presents mathematical models, the ranking effects by Pareto charts, response surface method and the multiple ANOVA analysis of variance. It showed the main effect of laser power in determining the weld characteristics.

Danut Iordachescu et al[11] This paper is reviewing the metal transfer according to the progress made in the welding sources and techniques development. It critically analysis the actual classification of the metal transfer in GMA welding, describing the relevant phenomenon and proposing improvements, to make the understanding and the work easier in the field of arc welding. Basic concepts are overviewed and defined or re-defined: fundamental transfer modes, natural *vs.* controlled transfer mode, variants *vs.* variances, mixed *vs.* combined modes, drop spray transfer. The new classification is simpler, without loosing the logic of numbering, both from fundamental point of view (the physics of the transfer) and the technological one (the increasing of the values of the welding parameters).

Ceyhan Yildiz et al[12] highlighted the effects of various welding parameters on welding penetration in Erdemir 6842 steel having 2.5 mm thickness welded by robotic gas metal arc welding were investigated. The welding current, arc voltage and welding speed were chosen as variable parameters. The depths of penetration were measured for each specimen after the welding operations and the effects of these parameters on penetration were researched. The welding currents were chosen as 95, 105, 115 A, arc voltages were chosen as 22, 24, and 26 V and the welding speeds were chosen as 40, 60 and 80 cm/min for all experiments. As a result of this study, it was obvious that increasing welding current increased the depth of penetration. In addition, arc voltage is another parameter in incrimination of penetration. However, its effect is not as much as current. The highest penetration was observed in 60 cm/min welding speed.

B.Y. Kanga et al[13] from korea institute of technology elaborates on Discrete alternate supply of shielding gas which is a new technology that alternately supplies the different kinds of shielding gases in weld zone. As the new developed methods compared to the previous general welding with a mixing supply of shielding gas, it cannot only increase the welding quality, but also reduce the energy by 20% and the emission rate of fume. As a result, under the same welding conditions, compared with the welding by supplying pure argon, argon + 67% helium mixture by conventional method and the welding by supplying alternately pure argon and pure helium by alternate method showed the increased welding speed. The alternate method with argon and helium compared with the conventional methods of pure argon and argon + 67% helium mixture produced the lowest degree of welding distortion.

Eiji Akiyama et al[14] studied the quantitative relationship between notch tensile strength and diffusible hydrogen content for the AISI 4135 steel at 1320MPa. The notch tensile strength was obtained by means of a slow strain rate test on circumferentially notched round bar specimens with stress concentration factors of 2.1, 3.3 and 4.9 after hydrogen charging, and the diffusible hydrogen content was then measured by thermal desorption spectrometry analysis. The diffusible hydrogen has been found to decrease the notch tensile strength in a power law manner, and the decrease is more prominent at a higher stress concentration factor. The notch root have shown that the local fracture stress decreases with increasing local hydrogen concentration as the diffusible hydrogen content or stress concentration factor increases, resulting in the decrease in the notch tensile strength.

Olivera Popovic et al[15] according to them the welding heat input has a great influence on the weldments properties. This paper described the influence of welding heat input on the weld metal toughness of high-carbon steel surface welded joint. The steel is surfaced with self-shielded wire, with three different heat inputs (6.5; 10.5 and 16 kJ/cm). Total impact energy, as well as crack initiation and crack propagation energies, are estimate at three testing temperatures. It has been established that with heat input increase toughness decreases and that heat input of 7 kJ/cm is optimal for weld metal toughness of investigated steel. Crack initiation energy is higher than crack propagation energy at all testing temperatures.

Wang Juan et al[16] studied the effect of heat input on impact toughness . They used the super-high strength steel which has very high strength (UTS > 1200 MPa).the super high strength of the weld in heat affected zone was carried out by using Scanning electron microscope (SEM),Transmission electron microscope(TEM) and electron diffraction technique. Test results indicated that the structure of HAZ of HQ130 steel was mainly lath martensite (ML), in which there were a lot of dislocations in the sub-structure inside ML lath, the dislocation density was about (3-9) 10^12/cm2. No obvious twin was observed in the HAZ under the condition of normal weld heat input. By controlling weld heat input (E < 20 kJ/cm), the impact toughness in the HAZ can be assured.

V.Balausamy et al[17] studied the effect of process parameters on mechanical properties of friction stir welding using full factorial . The Analysis of variance is employed to investigate the effect of input parameters on mechanical properties of weld a co-relation was established between tool rotation speed and weld speed with mechanical properties multiple linear regression. This study indicates that weld speed is the main input parameters that has the highest statistical influence on mechanical properties.

H.R. Ghazvinloo et al[18] studied the effect of variables on fatigue life and impact properties. The effect of processing variables on fatigue life, impact energy and bead penetration of AA6061 joints produced by MIG robotic welding process was analyzed in the present study. Different samples were obtained by employing arc voltages of 20, 23 and 26 V, welding currents of 110, 130 and 150 A, welding speeds of 50, 60 and 70 cm/min. Results were clearly illustrated that when heat input increases, fatigue life of weld metal decreases whereas impact energy of weld metal increases in first and then drops significantly. A linear increase in depth of penetration with increasing welding current and arc voltage was also observed. The biggest penetration in this investigation was observed for 60 cm/min welding speed.

Mersida Manjgo et al[19] studied the behavior of the plates with a surface notch under tensile external loading and experimentally and numerically analyzed it. The specimens were made of micro-alloyed steel NIOMOL 490 K, welded by MAG (CO_2) welding method. Surface notches were machined by the spark erosion method in the weld metal and heat affected zone. A finite element analysis of the specimens subjected to the tensile external loading is performed, with a simplified treatment of the heat affected zone mechanical properties. Obtained results are compared with the results of the experimental investigation, and a satisfactory agreement for the specimens containing the weld metal notch is observed.

Yupiter Hp Maurung et al[20] in this paper investigated the correlation between welding parameters and bead geometry of 3F fillet joint welded by GMAW in downhill position. The consumable is ER70S-6 1.2mm solid wire and shielded by Carbon Dioxide. Articulated welding robot performs the welding of 6mm carbon steel T-joint coupons. The welding parameters are arc voltage, welding current and welding speed, while the wire extension is set at constant at 13mm. The experimental results are tabulated; the correlations between the bead geometry and welding parameter are displayed graphically. Mathematical formulas are developed to match the graphical profiles. A calculator is developed to display the values of weld bead geometry for any value of welding parameter and vice versa. The deviation between predicted weld bead geometry and actual experimental record is less than 1.0mm, it is validated as accurate

Koray Kokemli et al[21] studied the effect of atmosphere in GMAW process. Therefore, a controlled atmosphere cabinet was developed for GMAW process. Low carbon steel combinations were welded with classical GMAW process in argon atmosphere as well as controlled atmosphere cabinet by using similar welding parameters. The mechanical and metallurgical properties of both weldments were evaluated. Result shows that toughness of the weld metal that was obtained in the controlled atmosphere cabinet much higher than that of classical GMAW process. The metallographic examination also clarified that there was not any gas porosity and inclusion in the weld metal compared with classical process

P. Yayla et al[22] in this study used different welding techniques to evaluate the mechanical performance of weldments of HY-80 steel. Weldments are prepared using different welding processes such as shielded metal arc welding, gas metal arc welding, and submerged metal arc. The objective was to determine the optimum welding method for the steel. After welding, the effects of welding methods on weld metal microstructure and mechanical properties including weld metal tensile strength and Charpy V-notch impact toughness over the temperature range -20C to 20C are investigated. Charpy impact and tensile tests are performed on standard notched specimens obtained from the welded and main sections of the material. The hardness distribution measurements on the differently welded specimens are conducted in order to gain a deep insight of different welding methods. The present work has revealed that with the optimum welding parameters the HY80 steel could be welded effectively with the utilised welding methods without any post-weld heat treatment.

Sunil pandey et al[23] studied the effect of welding parameters on Manganese, silicon, carbon and chromium content of the weld metal, mathematical models were developed and then tested by analysis of variance technique(ANOVA), which were found adequate with in the selected range of welding parameters. It was observed that the welding parameters and basicity index affected the Mn,Si and C content of the weld metal. Cr content of the weld metal was influenced by the basicity index of the flux used.

S.P.Teewari et al[24]:- Studied the effect of various welding parameters on the weldability of Mild Steel specimens having dimensions 50mm× 40mm× 6 mm welded by metal arc welding were investigated. The welding current, arc voltage, welding speed, heat input rate are chosen as welding parameters. The depth of penetrations were measured for each specimen after the welding operation on closed butt joint and the effects of welding speed and heat input rate parameters on depth of penetration were investigated.

2.3Summary:- In this chapter different research papers published in the journals of international repute were studied and the end results of different experiments carried out by the researchers around the world were written. After the review of these papers it was decided to study the effects of process parameters on the mechanical behaviour in GMAW. The literature review gives a detailed knowledge about how experiments should be designed, performed and how to generate, analyse and validate the mathematical models.

CHAPTER -3

GAS METAL ARC WELDING

3.1 Introduction

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a welding process in which an electric arc forms between a consumable wire electrode and the workpiece metal(s), which heats the workpiece metal(s), causing them to melt, and join. Along with the wire electrode, a shielding gas feeds through the welding gun, which shields the process from contaminants in the air. The process can be semi-automatic or automatic. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it provided faster welding time compared to other welding processes. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. GMAW overcomes the restriction of limited electrode length . Welding can be done in all positions. Deposition rates are significantly higher . Because the wire feed is continuous, long welds can be deposited without stops and starts. Minimal post weld cleaning is required due to the absence of a heavy slag. Due to these properties gas metal arc welding is in high demand in industries. [25,26]

3.2Principle of Operation

The GMAW process incorporates the automatic feeding of a continuous, consumable electrode that is shielded by an externally supplied gas**.** After initial settings by the operator, the equipment provides for automatic self-regulation of the electrical characteristics of the arc. Therefore, the only manual controls required by the welder for semiautomatic operation are the travel speed and direction, and gun positioning.

However in this project travel speed was also semi-automaticaly controlled. The process is illustrated in fig **3.1**

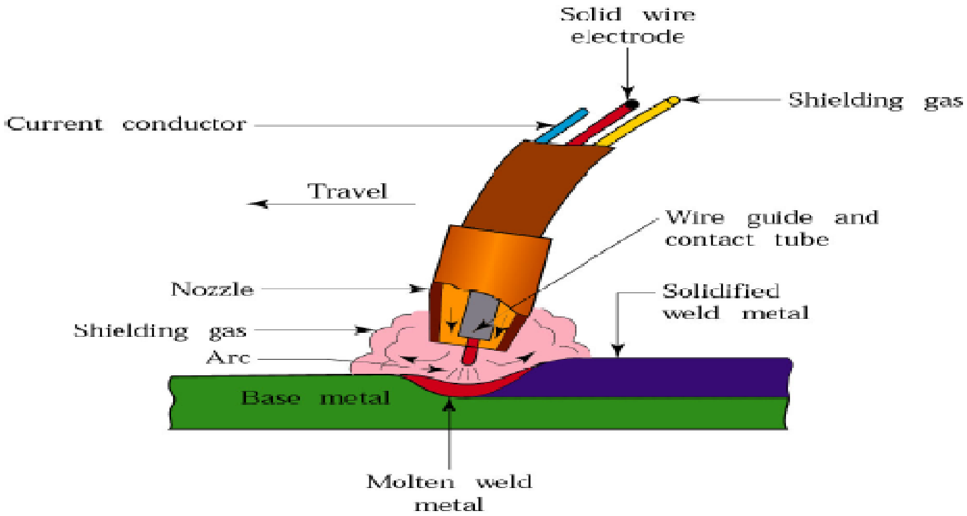


FIG 3.1:- Gas metal arc welding process[27]

Given proper equipment and settings, the arc length and the current (wire feed speed) are automatically maintained, Equipment required for GMAW is shown in Figure **3.2**. The gun guides the consumable electrode and conducts the electrical current and shielding gas to the work, thus providing the energy to establish and maintain the arc and melt the electrode as well as the needed protection from the ambient atmosphere. Two combinations of electrode feed units and power supplies are used to achieve the desirable self-regulation of arc length. Most commonly this regulation consists of a constant-potential (voltage) power supply (characteristically providing an essentially flat voltampere curve) in conjunction with a constant-speed electrode feed unit. Alternatively a constant-current Power supply provides a drooping volt-ampere curve, and the electrode feed unit is arc-voltage controlled. With the constant potential/constant wire feed combination, changes in the torch position cause a change in the welding current that exactly matches the change in the electrode stick-out (electrode extension), thus the arc length remains fixed, For example, an increased stick-out produced by withdrawing the torch reduces the current output from the power supply, thereby maintaining the same resistance heating of the electrode.

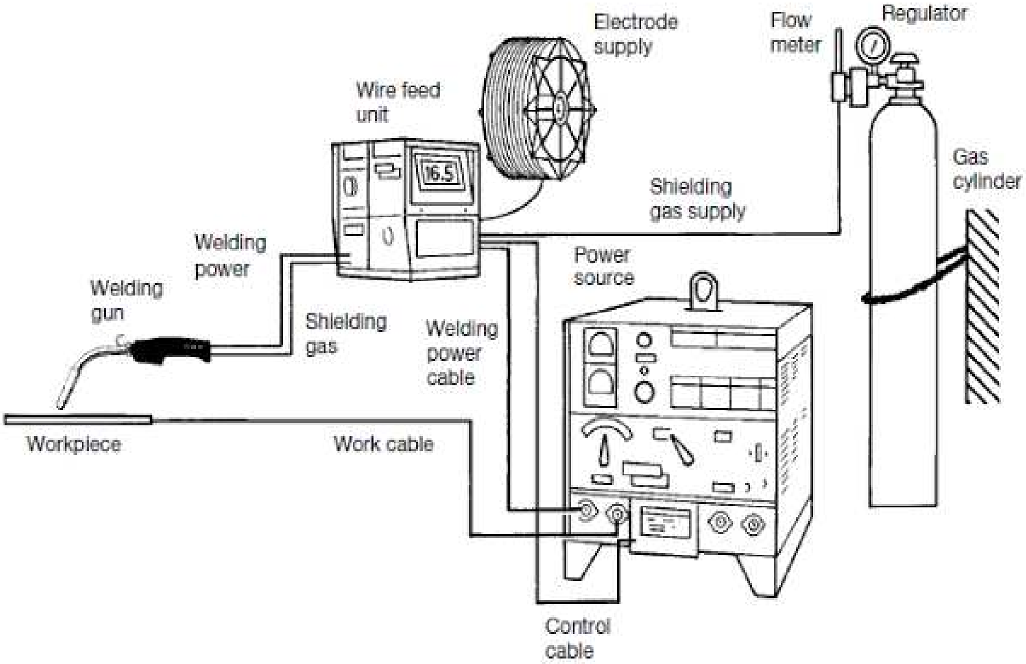


Fig 3.2- Gas metal arc welding equipment[26]

In the alternative system, self-regulation results when arc voltage fluctuations readjust the control circuits of the feeder, which appropriately changes the wire feed speed. In some cases (welding aluminum, for example), it may be preferable to deviate from these standard combinations and couple a constant-current power source with a constant- speed electrode feed unit. This combination provides only a small degree of automatic self-regulation, and

therefore requires more operator skill in semiautomatic welding. However, some users think this combination affords a range of control over the arc energy (current) that may be important in coping with the high thermal conductivity of aluminum base metals.

3.3 GMAW welding equipments :-

3.3.1 Power source- Power sources incorporate output characteristics designed to optimize the arc performance for a given welding process. For GMAW, the output characteristics fall into two main categories:

- constant current
- constant voltage.

Out of these two the constant voltage type is generally used as it helps in maintaining a constant arc length with help of automatic wire feeder. The figure 3.3 shows the unaffected arc length even when stick out length is varied.

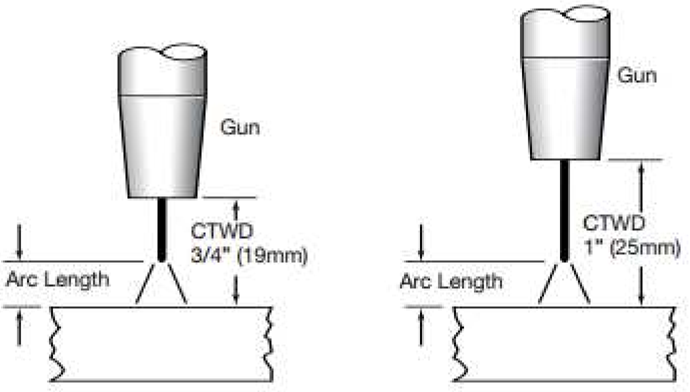


Fig 3.3:- Unaffected arc length with change in CTWD[28]

3.3.2 The wire feeder :-The wire feeder is a device that feeds the electrode wire. While the power source controls the voltage output, increasing or decreasing the wire feed speed (WFS) on the wire feeder increases or decreases the welding amperage. It is one of the most important part of gas metal arc welding process.

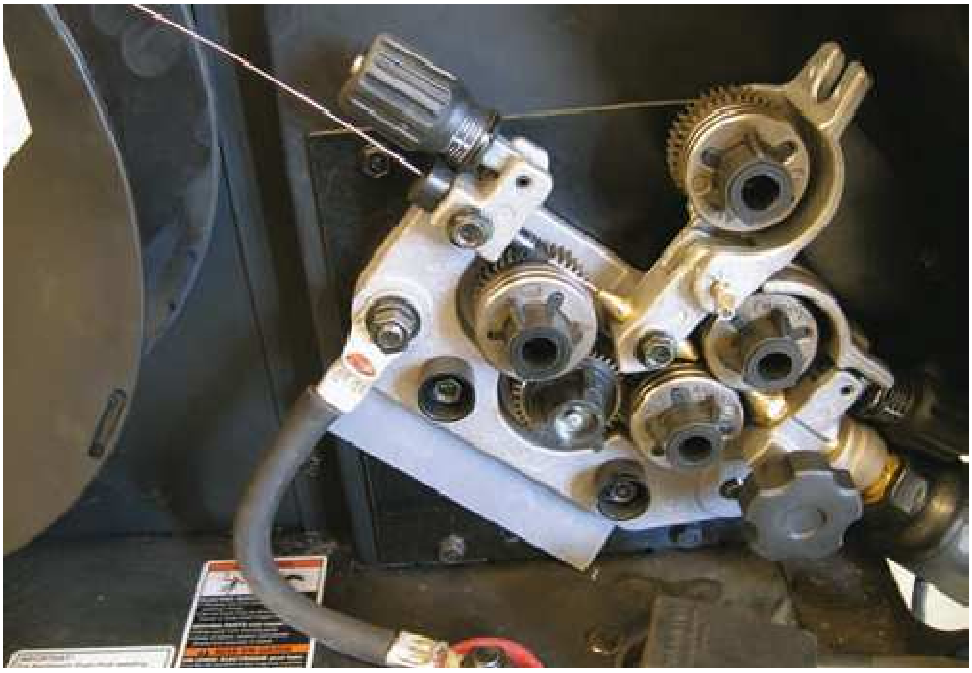


Fig 3.4:- The wire feeder (two roll drive system)[29]

3.3.3 The welding gun:- The typical GMAW welding gun has a number of key parts—a control switch, a contact tip, a power cable, a gas nozzle, an electrode conduit and liner, and a gas hose. The control switch, or trigger, when pressed by the operator, initiates the wire feed, electric power, and the shielding gas flow, causing an electric arc to be struck. The contact tip, normally made of copper and sometimes chemically treated to reduce spatter, is connected to the welding power source through the power cable and transmits the electrical energy to the electrode while directing it to the weld area.

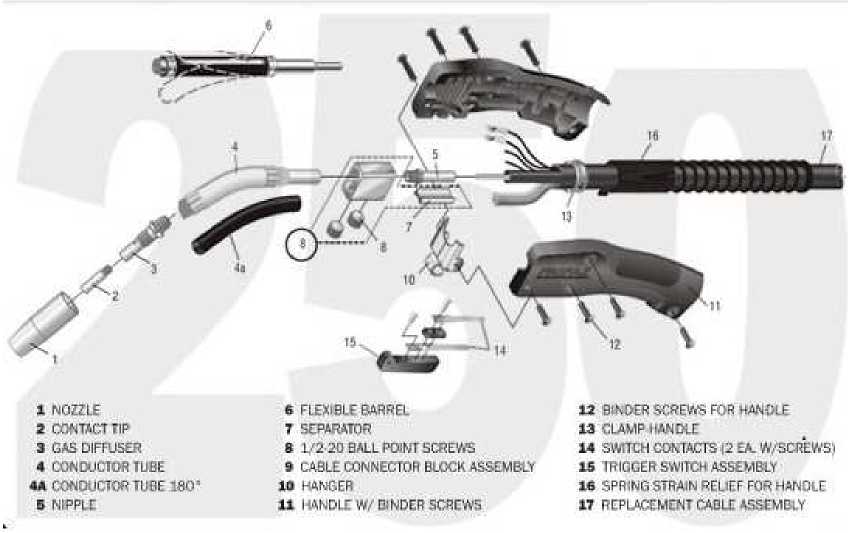


Fig 3.5:- Exploded view of GMAW torch[30].

3.3.4Electrode:- Electrode is most important part of GMAW welding process. Its selection is based primarily on the composition of the metal being welded, the process variation being used, joint design and the material surface conditions.. In general the weld metal should have mechanical properties similar to those of the base material with no defects such as discontinuities, entrained contaminants or porosity within the weld. All commercially available electrodes contain deoxidizing metals such as silicon, manganese, titanium and aluminum in small percentages to help prevent oxygen porosity. Some contain denitriding metals such as titanium and zirconium to avoid nitrogen porosity. Depending on the process variation and base material being welded the diameters of the electrodes used in GMAW typically range from 0.7 to 2.4 mm (0.028–0.095 in) but can be as large as 4 mm (0.16 in).

3.4.5Shielding gas:- Shielding gases are necessary for gas metal arc welding to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. This problem is common to all arc welding processes; for example, in the older Shielded-Metal Arc Welding process (SMAW), the electrode is coated with a solid flux which evolves a protective cloud of carbon dioxide when melted by the arc. In GMAW, however, the electrode wire does not have a flux coating, and a separate shielding gas is employed to protect the weld. The choice of a shielding gas depends on several factors, most importantly the type of material being welded and the process variation being used. Pure inert gases such as argon and helium are only used for nonferrous welding; with steel they do not provide adequate weld penetration (argon) or cause an erratic arc and encourage spatter (with helium). Pure carbon dioxide, on the other hand, allows for deep penetration welds but encourages oxide formation, which adversely affect the mechanical properties of the weld.[12] Its low cost makes it an attractive choice.

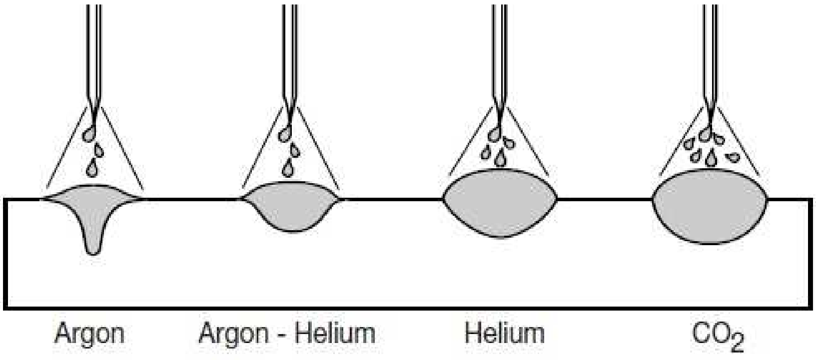


Fig:-3.6 Bead contour and penetration patterns for various shielding gases[25]

3.3.6 Flow meters:- There are many types of shielding gases which are used in gas metal arc welding ,the properties of the weld (such as penetration, bead width height and reinforcement height) depend not only on the type of shielding gas but also on the flow rate of the gas.

Fig 3.7:- Flow meters[27]

3.4 Modes of metal transfer[34]:- the characteristics of GMAW process are best described in terms of the three basic means by which metal is transferred from the electrode to the work. These are ;-

3.4.1 Globular transfer

GMAW with globular metal transfer is considered the least desirable of the three major GMAW variations, because of its tendency to produce high heat, a poor weld surface, and spatter. The method was originally developed as a cost efficient way to weld steel using GMAW, because this variation uses carbon dioxide, a less expensive shielding gas than argon. Adding to its economic advantage was its high deposition rate, allowing welding speeds of up to 110 mm/s (250 in/min). As the weld is made, a ball of molten metal from the electrode tends to build up on the end of the electrode, often in irregular shapes with a larger diameter than the electrode itself. When the droplet finally detaches either by gravity or short circuiting, it falls to the workpiece, leaving an uneven surface and often causing spatter.

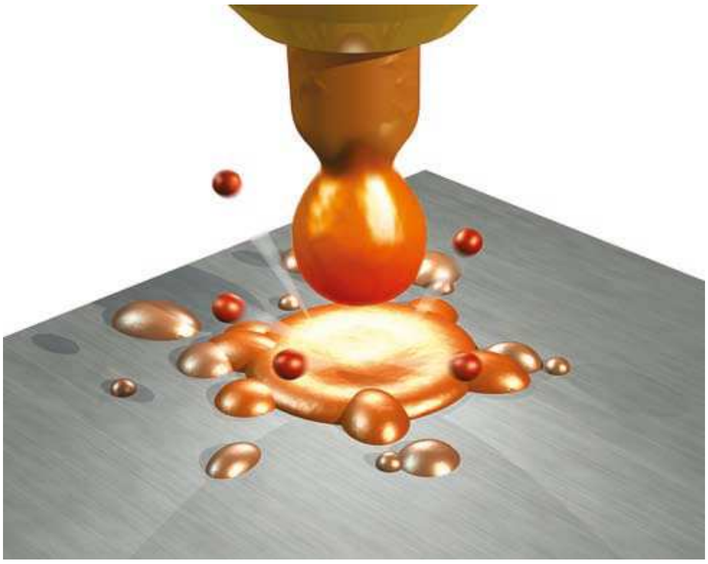


Fig 3.8:- Globular transfer[42]

As a result of the large molten droplet, the process is generally limited to flat and horizontal welding positions. The high amount of heat generated also is a downside, because it forces the welder to use a larger electrode wire, increases the size of the weld pool, and causes greater residual stresses and distortion in the weld area.

3.4.2 Short-circuiting transfer

Further developments in welding steel with GMAW led to a variation known as short-circuit transfer (SCT) or short-arc GMAW, in which the current is lower than for the globular method. As a result of the lower current, the heat input for the short-arc variation is considerably reduced, making it possible to weld thinner materials while decreasing the amount of distortion and residual stress in the weld area. As in globular welding, molten droplets form on the tip of the electrode, but instead of dropping to the weld pool, they bridge the gap between the electrode and the weld pool as a result of the lower wire feed rate. This causes a short circuit and extinguishes the arc, but it is quickly reignited after the surface tension of the weld pool pulls the molten metal bead off the electrode tip(as shown in fig 3.9).

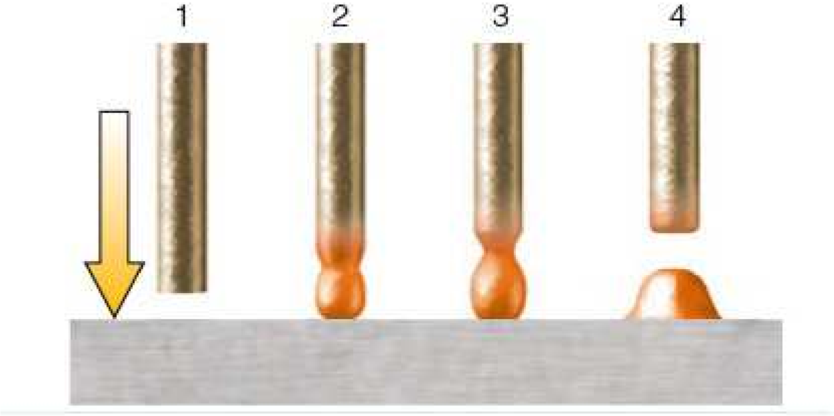


Fig 3.9:- short circuit transfer[42]

This process is repeated about 100 times per second, making the arc appear constant to the human eye. This type of metal transfer provides better weld quality and less spatter than the globular variation, and allows for welding in all positions, albeit with slower deposition of weld material. Setting the weld process parameters (volts, amps and wire feed rate) within a relatively narrow band is critical to maintaining a stable arc: generally between 100 to 200 amperes at 17 to 22 volts for most applications. Also, using short-arc transfer can result in lack of fusion and insufficient penetration when welding thicker materials, due to the lower arc energy and rapidly freezing weld pool. Like the globular variation, it can only be used on ferrous metals

3.4.3 Spray transfer

Spray transfer GMAW was the first metal transfer method used in GMAW, and well-suited to welding aluminum and stainless steel while employing an inert shielding gas. In this GMAW process, the weld electrode metal is rapidly passed along the stable electric arc from the electrode to the workpiece, essentially eliminating spatter and resulting in a high-quality weld finish. As the current and voltage increases beyond the range of short circuit transfer the weld electrode metal transfer transitions from larger globules through small droplets to a vaporized stream at the highest energies. Since this vaporized spray transfer variation of the GMAW weld process requires higher voltage and current than short circuit transfer, and as a result of the higher heat input and larger weld pool area (for a given weld electrode diameter), it is generally used only on workpieces of thicknesses above about 6.4 mm (0.25 in). Also, because of the large weld pool, it is often limited to flat and horizontal welding positions and sometimes also used for vertical-down welds. It is generally not practical for root pass welds.When a smaller electrode is used in conjunction with lower heat input, its versatility increases. The maximum deposition rate for spray arc GMAW is relatively high about 60 mm/s (150 in/min)

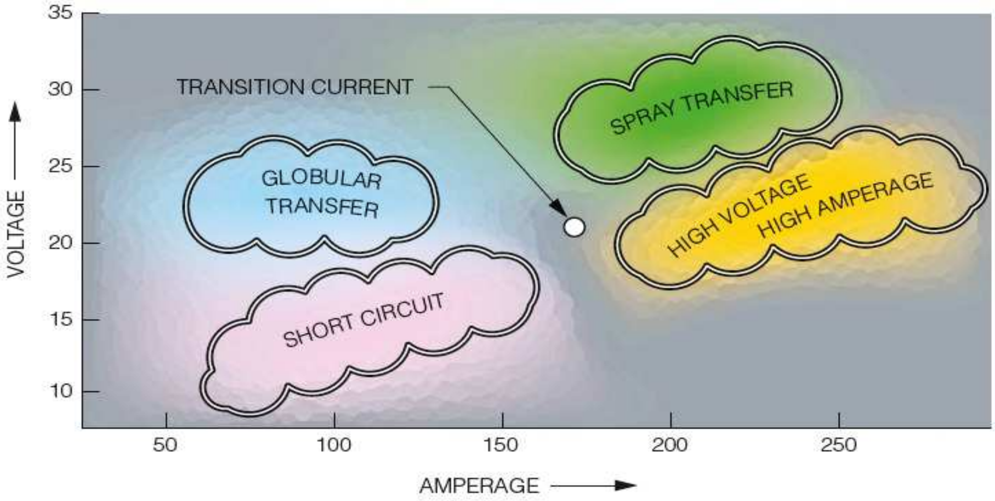


Fig 3.10:- Area of modes of transfer[42]

3.4.4 Pulsed-spray transfer

A variation of the spray transfer mode, pulse-spray is based on the principles of spray transfer but uses a pulsing current to melt the filler wire and allow one small molten droplet to fall with each pulse. The pulses allow the average current to be lower, decreasing the overall heat input and thereby decreasing the size of the weld pool and heat-affected zone while making it possible to weld thin workpieces. The pulse provides a stable arc and no spatter, since no short-circuiting takes place. This also makes the process suitable for nearly all metals, and thicker electrode wire can be used as well. In comparison with short arc GMAW, this method has a somewhat slower maximum speed (85 mm/s or 200 in/min) and the process also requires that the shielding gas be primarily argon with a low carbon dioxide concentration. Additionally, it requires a special power source capable of providing current pulses with a frequency between 30 and 400 pulses per second. However, the method has gained popularity, since it requires lower heat input and can be used to weld thin workpieces, as well as nonferrous materials.

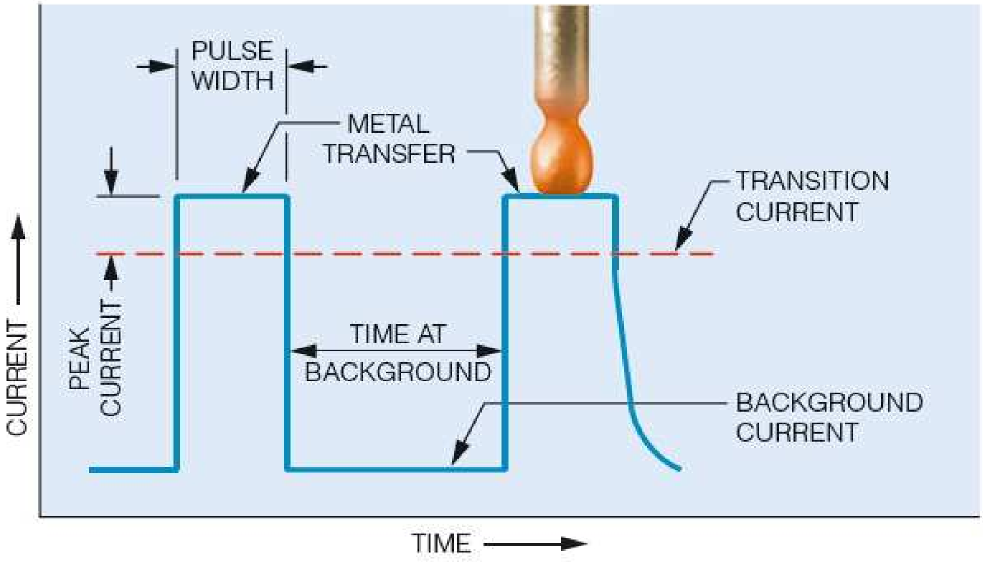


Fig 3.11:- pulsed spray transfer[42]

3.5 Process variables:- the following are some of the variables that affect weld penetration, bead geometry ,mechanical properties and overall weld quality:

1) Welding current (electrode feed speed)

2) Polarity

3) Arc voltage (arc length)

4) Travel speed

5) Electrode extension

6) Electrode orientation (trail or lead angle)

7)Weld joint position

8) Electrode diameter

9) Shielding gas composition and flow rate

Knowledge and control of these variables is essential to consistently produce welds of satisfactory quality. These variables are not completely independent, and changing one generally requires changing one or more of the others to produce the desired results.There is no single set of parameters that gives optimum results in every case.

3.5.1 Welding Current:-When all other variables are held constant, the welding amperage varies with the electrode feed speed or melting rate in a nonlinear relation. As the electrode feed speed is varied, the welding amperage will vary in a like manner if a constant-voltage power source is used. This relationship of welding current to wire feed speed for carbon steel electrodes is shown in Figure 3.12**.** At the low-current levels for each electrode size, the curve is nearly linear. However, at higher welding currents, particularly with small diameter electrodes, the curves become nonlinear, progressively increasing at a higher rate as welding amperage increases. This is attributed to resistance heating of the electrode extension beyond the contact tube. The curves can be approximately represented by the equation

$WFS = \boldsymbol{aI} + BLI^{\wedge 2}$

elsewhere

WFS = the electrode feed speed, in./min (mm/s)

a = a constant of proportionality for anode or cathode heating. Its magnitude is
dependent
upon polarity, composition, and other factors.

$\boldsymbol{b}$ = constant of proportionality for electrical resistance heating.

L = the electrode extension or stick out.

I = the welding current.

As shown in Figures 3.12, when the diameter of the electrode is increased (while maintaining the same electrode feed speed), a higher welding current is required. The relationship between the electrode feed speed and the welding current is also affected by the electrode chemical composition. [18]

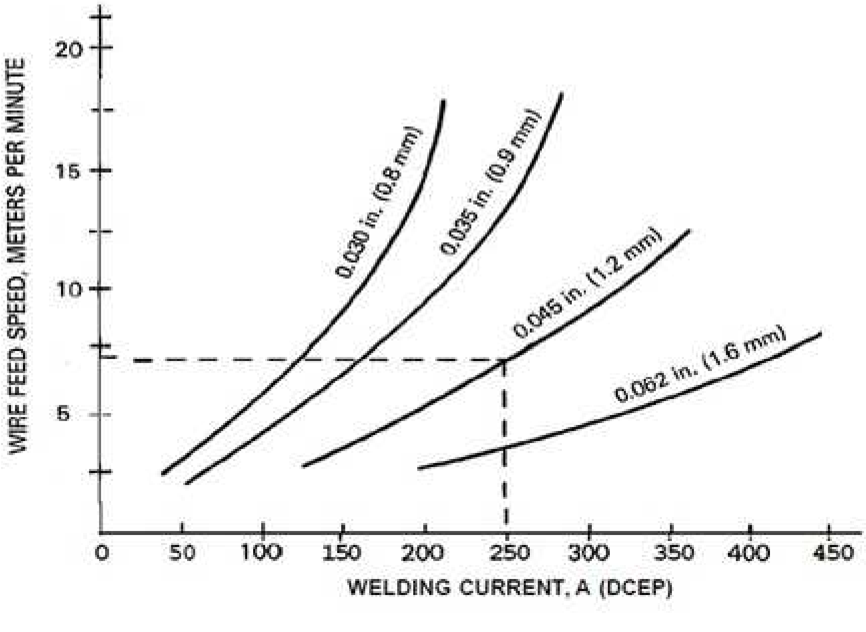


Fig 3.12:-Current Vs Wire Feed Speeds for Carbon Steel Electrodes[35]

3.5.2 Polarity:- The term *polarity* is used to describe the electrical connection of the welding gun with relation to the terminals of a direct current power source. When the gun power lead is connected to the positive terminal, the polarity is designated as direct current electrode positive (DCEP), arbitrarily called *reverse polarity*. When the gun is connected to the negative terminal, the polarity is designated as direct current electrode negative (DCEN), originally called *straight polarity*. The vast majority of GMAW applications use direct current electrode positive (DCEP). This condition yields a stable arc, smooth metal transfer, relatively low spatter, good weld bead characteristics and greatest depth of penetration for a wide range of welding currents. Direct current electrode negative (DCEN) is seldom used because axial spray transfer is not possible without modifications that have had little commercial acceptance. DCEN has a distinct advantage of high melting rates that cannot be exploited because the transfer is globular. Attempts to use alternating current with the GMAW process have generally been unsuccessful.

3.5.3 Arc Voltage (Arc Length):- These are terms that are often used interchangeably. It should be pointed out, however, that they are different even though they are related. With GMAW, arc length is a critical variable that must be carefully controlled. For example, in the spray-arc mode with argon shielding, an arc that is too short experiences momentary short circuits. They cause pressure fluctuations which pump air into the arc stream, producing porosity or embrittlement due to absorbed nitrogen. Should the arc be too long, it tends to wander, affecting both the penetration and surface bead profiles. **A** long arc can also disrupt the gas shield, In the case of buried arcs with a carbon dioxide shield, a long arc results in excessive spatter as well **as** porosity; if the arc is too short, the electrode tip short circuits the weld pool, causing instability. Arc length is the independent variable. Arc voltage depends on the arc length as well as many other variables, such as the electrode composition and dimensions, the shield gas, the welding technique and, since it often is measured at the power supply, even the length of the welding cable. Arc voltage is an approximate means of stating the physical arc length in electrical terms.With all variables held constant, arc voltage is directly related to arc length. Even though the arc length is the variable of interest and the variable that should be controlled, the voltage is more easily monitored.

3.5.4 Travel speed:- It is the linear rate at which the arc is moved along the weld joint. With all other conditions held constant, weld penetration is a maximum at an intermediate travel speed. When the travel speed is decreased, the filler metal deposition per unit length increases. At very slow speeds the welding arc impinges on the molten weld pool, rather than the base metal, thereby reducing the effective penetration. A wide weld bead is also a result. As the travel speed is increased, the thermal energy per unit length of weld transmitted to the base metal from the arc is at first increased, because the arc acts more directly on the base metal. With further increases in travel speed, less thermal energy per unit length of weld is imparted to the base metal. Therefore, melting of the base metal first increases and then decreases with increasing travel speed. As travel speed is increased further, there is a tendency toward undercutting along the edges of the weld bead because there is insufficient deposition of filler metal to fill the path melted by the arc.

3.5.5 Electrode Extension:-

The electrode extension is the distance between the end of the contact tube and the end of the electrode. An increase in the electrode extension results in an increase in its electrical resistance. Resistance heating in turn causes the electrode temperature to rise, and results in a small increase in electrode melting rate. Overall, the increased electrical resistance produces a greater voltage drop from the contact tube to the work. This is sensed by the power source, which compensates by decreasing the current. That immediately reduces the electrode melting rate, which then lets the electrode shorten the physical arc length. Thus, unless there is an increase in the voltage at the welding machine, the filler metal will be deposited as a narrow, high-crowned weld bead. The desirable electrode extension is generally from ¼ to 1/2 in. ***(6*** to 13 mm) for short circuiting transfer and from 1/2 to 1 in. (13 to 25 mm) for other types of metal transfer.

3.5.6 Electrode Orientation :- As with all arc welding processes, the orientation of the welding electrode with respect to the weld joint affects the weld bead shape and penetration. Electrode orientation affects bead shape and penetration to a greater extent than arc voltage or travel speed. The electrode orientation is described in two ways: (1) by the relationship of the electrode **axis** with respect to the direction of travel (the travel angle), and (2) the angle between the electrode axis and the adjacent work surface (work angle). When the electrode points opposite from the direction of travel, the technique is called *backhand welding with a drag angle.* When the electrode points in the direction of travel, the technique is *forehand welding with a lead angle.* The electrode orientation and its effect on the width and penetration of the weld are illustrated in Figures 3.13 (A), (B), and (C).[18]

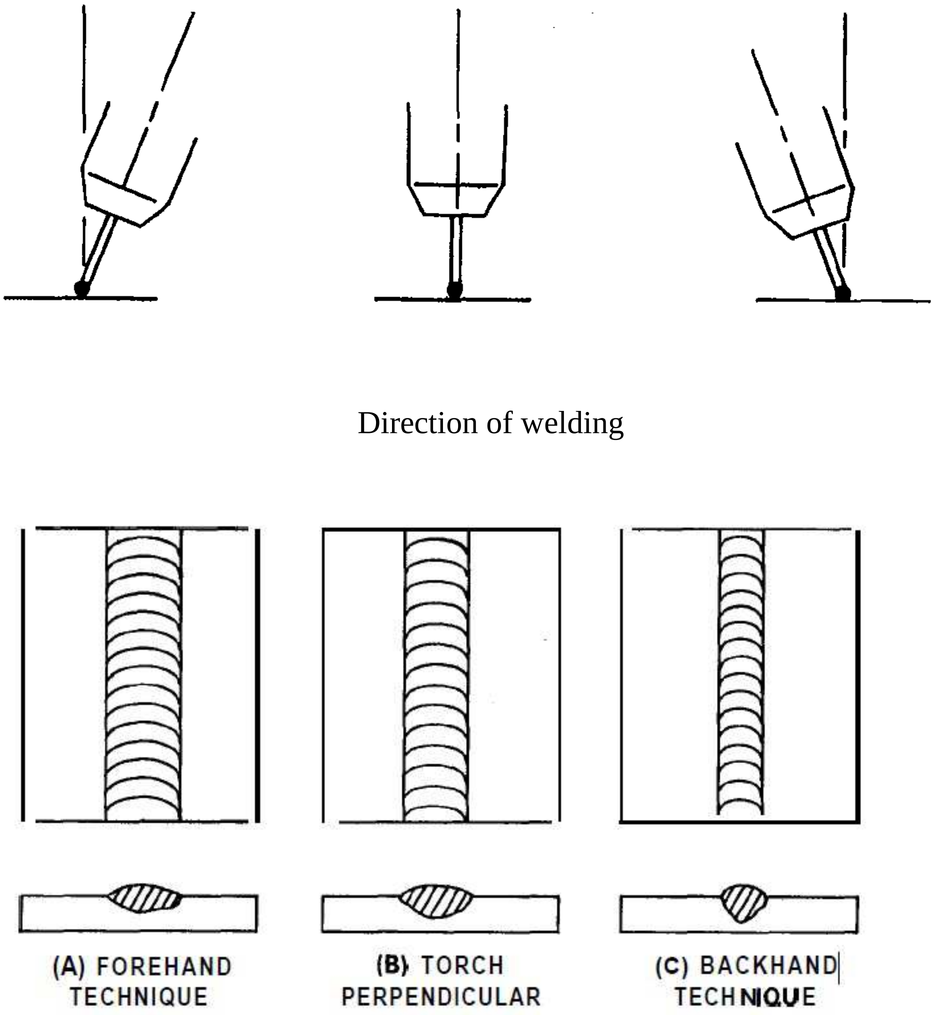


Fig 3.13 :- Effect of electrode position and welding technique[25]

When the electrode is changed from the perpendicular to a lead angle technique with all other conditions unchanged, the penetration decreases and the weld bead becomes wider and flatter. Maximum penetration is obtained in the flat position with the drag technique, at a drag angle of about *25* degrees from perpendicular. The drag technique also produces a more convex, narrower bead, a more stable arc, and less spatter on the workpiece. For all positions, the electrode travel angle normally used is a drag angle in the range of 5 to 15 degrees for good control and shielding of the molten weld pool.

For some materials, such as aluminum, a lead technique is preferred. This lead technique provides a “cleaning action” ahead of the molten weld metal, which promotes wetting and reduces base metal oxidation.

3.5.7 Weld Joint Position: Most spray type GMAW is done in the flat or horizontal positions, while at low-energy levels, pulsed and short circuiting GMAW can be used in all positions. Fillet welds made in the flat position with spray transfer are usually more uniform, less likely to have unequal legs and convex profiles, and are less susceptible to undercutting than similar fillet welds made in the horizontal position. To overcome the pull of gravity on the weld metal in the vertical and overhead positions of welding, small diameter electrodes are usually used, with either short circuiting metal transfer or spray transfer with pulsed direct current. The low-heat input allows the molten pool to freeze quickly. Downward welding progression is usually effective on sheet metal in the vertical position. When welding is done in the “flat” position, the inclination of the weld axis with respect to the horizontal plane will influence the weld bead shape, penetration, and speed. Uphill welding affects the fusion zone contour and the weld surface, as illustrated in Figure **3.14.**

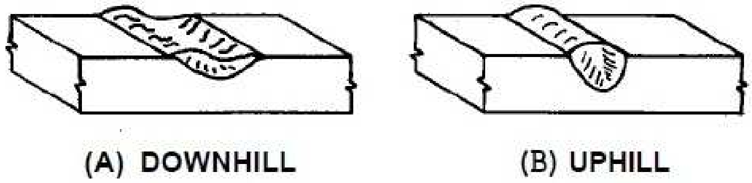


Fig 3.14:- Effect of Work Inclination on Weld Bead Shape[28]

The force of gravity causes the weld puddle to flow back and lag behind the electrode. The edges of the weld lose metal, which flows to the centre. As the angle of inclination increases, reinforcement and penetration increase, and the width of the weld decreases. The effects are exactly the opposite of those produced by downhill welding. When higher welding currents are used, the maximum usable angle decreases.

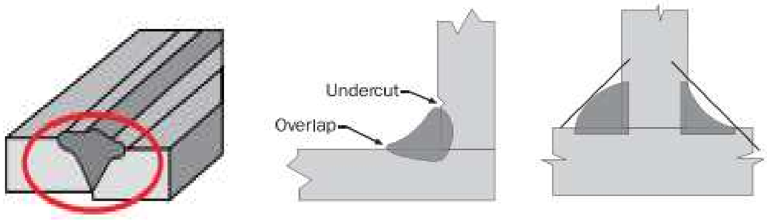
3.5.8 Electrode Size:-The electrode size (diameter) influences the weld bead configuration. **A** larger electrode requires higher minimum current than a smaller electrode for the same metal transfer characteristics. Higher currents in turn produce additional electrode melting and larger, more fluid weld deposits. Higher currents also result in higher deposition rates and greater penetration. However, vertical and overhead welding are usually done with smaller diameter electrodes and lower currents.

3.5.9 Shielding gas:- The characteristics of the various gases and their effect on weld quality and arc characteristics are discussed in detail earlier in this chapter.

3.6 Welding Defects :- Welding defects can greatly affect weld performance and longevity. Having an understanding of the various defects, their causes and remedies can help to ensure higher-quality and longer lasting welds.

3.6.1Geometric imperfections[27]:-Geometric imperfections refer to certain weld characteristics such as fit-up and weld bead shape as determined by visual inspection. They are an indication of poor workmanship and may be cause for concern if they exceed the acceptable limits of the quality control code being used for the weld inspection.

***Misalignment**:*-This type of geometric defect is generally caused by a setup/fit up problem, or trying to join plates of different thickness (see Figure 3.15 a).Overlap The protrusion of weld metal beyond the weld toe or weld root. It is caused by poor welding techniques and can generally be overcome by an improved weld procedure.



a:-Misalignment b:-Undercutting c:- convexity & concavity

Fig 3.15:- Geometric imperfections[27]

Undercutting:- Undercutting is one of the more severe welding defects. It is essentially an unfilled groove along the edge of the weld (see Figure 3.15b). The causes are usually associated with incorrect electrode angles, incorrect weaving technique, excessive current and travel speed. Undercutting can be avoided with careful attention to detail during preparation of the weld and by improving the welding process. It can be repaired in most cases by welding up the resultant groove with a smaller electrode.

Concave and convex welds*:-*Misshaped welds are caused by a combination of incorrect electrode current and speed. Excessive concavity (lack of reinforcement) results in insufficient throat thickness in relation to the nominated weld size (see Figure 3.15c). Excessive convexity results in poor weld contour. In multilayer welds this can give rise to slag inclusions, while in the finished weld it provides a poor stress pattern and a local notch effect at the toe of the weld. They can be avoided by using an appropriate electrode size, current and weaving pattern. Repair by either filling with further weld material or by grinding back to the base metal on each side of the weld and re-welding.

3.6.2 Cracking:-Cracks and planar discontinuities are some of the most dangerous, especially if they are subject to fatigue loading conditions. There are several different types of cracks and none are desired. They must be removed by grinding back (if superficial) or repaired by welding. Cracks can occur in the weld itself, the base metal, or the heat affected zone (HAZ) .Longitudinal cracks run along the direction of the weld and are usually caused by a weld metal hardness problem. This type of cracking is commonly caused by a cooling problem, the elements in the weld cooling at different rates. Longitudinal cracks can be prevented by welding toward areas of less constraint, preheating the elements to even out the cooling rates and by using the correct choice of welding consumables. If cracks do appear they can be repaired by grinding out or cutting the members apart and re-welding. A transverse crack is a crack in the base metal beginning at the toe of the weld. They are caused by transverse shrinkage stresses, and often indicate a brittleness problem in the heat affected zone. To prevent them it may require an increase in pre-heating or the use of a more ductile filler material. Underbead cracks are cracks in the unmelted parent metal of the heat affected zone and can be caused by hydrogen embrittlement (a process by which various metals become brittle and crack following exposure to hydrogen). To prevent these cracks use hydrogen controlled electrodes or preheat the elements being welded. These cracks can be repaired by gouging out and re-welding, but can only be found using non destructive testing (NDT)..

Lamellar tearing:-Lamellar tearing is a type of defect that is most likely to occur below a welded joint at points of high stress concentration . It is created by non-metallic inclusions being rolled into the hot plate metal during fabrication. These tears occur when weld metal is deposited on the surface of a joint where there is high restraint. Special joint design is one way to minimize this defect but the best precaution is to specify materials of adequate quality and test at the receiving inspection.

3.6.3 Inclusions:-Inclusions are generated by extraneous material such as slag, tungsten, sulfide and oxide inclusions becoming part of the weld. These defects are often associated with undercut, incomplete penetration and lack of fusion in welds. Insufficient cleaning between multi-pass welds and incorrect current and electrode manipulation can leave slag and unfused sections along the weld joint. Slag inclusions not only reduce cross sectional area strength of the joint but may serve as an initiation point for serious cracking. This defect can only be repaired by grinding down or gouging out and re-welding.

3.6.4 Porosity:-Porosity is a collective name describing cavities or pores caused by gas and non-metallic material entrapment in molten metal during solidification (see Figure 3.16).

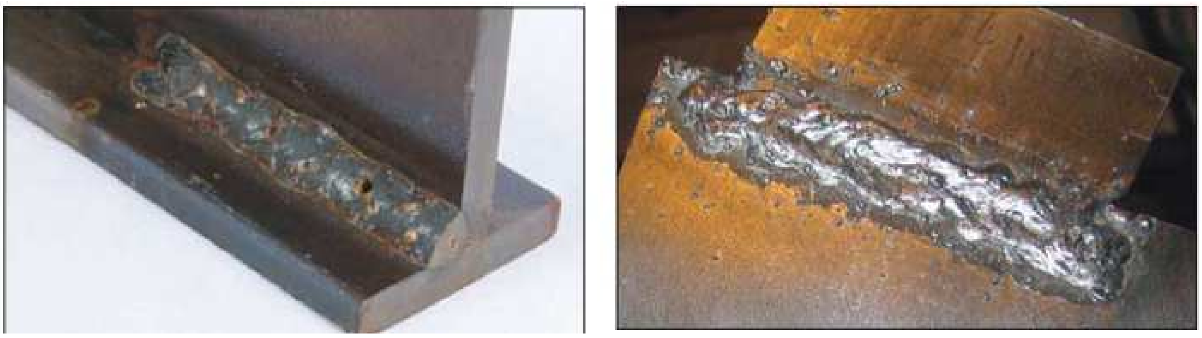


Fig 3.16:- Porosity(left) & spatter(right)[27,42]

There are many causes which include contamination, inadequate shielding, unstable arc, arc gap too short and poor welding technique in general. Porosity can be minimized in many different ways by the proper selection of electrodes and/or filler materials, improved welding techniques, more attention to the work area during weld preparation and a slower speed to allow gasses time to escape. The effects of porosity on performance depend on quantity, size, alignment, and orientation to stresses. When clustered at the weld's centre, porosity is not considered a dangerous fatigue promoter, or detrimental to fatigue resistance, although it may reduce the static stress carrying capacity of the weld.

3.6.5 Incomplete fusion/penetration:-Incomplete fusion or penetration is an internal planar discontinuity that is difficult to detect and evaluate, and very dangerous. It occurs when the weld metal does not form a cohesive bond with the base metal or when the weld metal does not extend into the base metal to the required depth, resulting in insufficient throat thickness

3.6.6 Weld damage:-Hammer marks and arc strikes Arc strikes appear as localized spots of remelted metal. Hammer strikes are small dints or nicks. They are caused by excessive force when using a chipping hammer, careless handling of the welding electrode holder and from inadvertent or careless arc manipulation. They must be avoided, and any traces removed. These imperfections can lead to small cracks in the heat-affected zone of the weld metal and can cause localised stress concentrations.

3.6.7 Craters:-Craters are visually inspectable depressions that indicate improper weld terminations, usually with the presence of radial cracks. They should be avoided if possible; the best way to do this is to ensure that correct welding techniques are used.

3.6.8 Spatter:-Metal drops expelled from the weld that stick to surrounding surfaces. Spatter can be minimized by correcting the welding conditions and should be eliminated by grinding when present see fig 3.16.

3.7USES AND ADVANTAGES:-

The uses of the process are, of course, dictated by its advantages, the most important of which are the following:

(1) It is the only consumable electrode process that can be used to weld all commercial metals and alloys.

(2) GMAW overcomes the restriction of limited electrode length encountered with shielded metal arc welding.

(3) Welding can be done in all positions, a feature not found in submerged arc welding.

(4) Deposition rates are significantly higher than those obtained with shielded metal arc welding.

(5) Welding speeds are higher than those with shielded metal arc welding because of the continuous electrode feed and higher filler metal deposition rates.

(6) Because the wire feed is continuous, long welds can be deposited without stops and starts.

(7) When spray transfer is used, deeper penetration is possible than with shielded metal arc welding, which may permit the use of smaller size fillet welds for equivalent strengths.

(8) Minimal postweld cleaning is required due to the absence of a heavy slag.

3.8LIMITATIONS:-

As with any welding process, there are certain limitations which restrict the use of gas metal arc welding. Some of these are the following:

(1) The welding equipment is more complex, more costly, and less portable than that for SMAW**.**

(2) GMAW is more difficult to use in hard-to-reach places because the welding gun is larger than a shielded metal arc welding holder.

(3) The welding arc must be protected against air drafts that will disperse the shielding gas. This limits outdoor applications unless protective shields are placed around the welding area.

(4) Relatively high levels of radiated heat and arc intensity can result in operator resistance to the process.

CHAPTER-4

EXPERIMENTAL SETUP

4.1Welding machine[39]:-

Gas metal Arc Welding (GMAW) process was used to weld the test specimens. The welding machine used is PHOENIX 521 (EWM). Table 4.1 illustrates the specification.

Table 4.1:- Welding machine specifications

Parameter **(Adjusting range welding current/voltage)**	**Value**
MIG/MAG	5A/14.3- 520A / 40V
Max. welding current at	
20°C ambient temperature:	
80%DC	520A
100%DC	450A
40°C ambient temperature:	
60%DC	520A
100%DC	420A
Load alternation	6min welding,4min break)
Open circuit voltage	79v

Mains voltage (tolerances)	3x400v(-25%t0+20%)
Frequency	50/60Hz
Mains fuse	3x35a
Max connection power	31.6KVA
Recommended generator reading	42.8KVA
COSØ/efficiency	.99/89%
Ambient temperature	-10°C to +40°C
Machine/torch cooling	Fan/gas
Work piece lead	95mm^2
Dimensions L/W/H(mm)	1100x455x950
Weight in kgs	109
Wire feed speed	0.5m/min-24m/min
Standard wire feed roller fitting	1mm/1.2mm (steel wire)
WF drive unit	4-roller(37)
Torch connection	Euro -central
Protection classification	IP23
Constructed to standards	IEC60974/EN60974/VDE0544 EN50199/VDE 0544

Fig4.1:- Front view of phoenix 521expert force arc MIG/MAG machine.

Fig 4.2:- Control panels of phoenix 521expert force arc MIG/MAG machine.

4.2 Material Information:- In this experiment mild steel plates of 6 mm thickness were used to weld with GMAW process with filler wire(ER70S6) manufactured by ESAB India Limited . The chemical, physical and mechanical properties of filler wire and base metal are given below **.**

Table 4.2:- Chemical composition of mild steel(Base metal)

Element	Fe	C	Si	Mn	Cu	Ni	Cr	Others
%	98.78	.22	.109	.331	.16	.124	.161	.115

Table 4.3:- Chemical composition of filler wire

Element	Fe	C	Si	Mn	Cu	Ni	Cr	Others
%	98.23	.11	.464	.812	.198	.038	.064	.084

Table 4.4:- Mechanical properties of filler wireER70S6:-

Properties	U.T.S (MPa)	Y.S(Mpa)	%Elongation	Impact strength(J) izod
Values	480	400	22	27 (at -20C)

Table 4.5:-Mechanical properties of Mild steel (base metal)

UTS(Mpa)	Y.S(Mpa)	% Elongation	N.T.S(Mpa)	Impact strength(izod)
505.971	441.18	21.789	610	65joules(at35^{0}C)

Table 4.6:- Physical properties of mild steel

Melting pt.(C)	Density(Kg/m$^{3)}$	Thermal conductivity (W.m^{-1}K^{-1})	Electrical conductivity (Ω^{-1}.m$^{-1)}$	Electrical Resistivity (Ω.m)
1415	7850	36-54	1176000	1.43x10^{-7}

4.3 Specially Designed Fixture :- In order to weld the two plates of dimensions 80x50x6mm^3 each a fixture was designed . some of its benefits were:-

1). Arrest distortion and twisting of two plates due to heating.

2). Avoid tech welds as plates were fixed firmly .

3) After the welding it was very difficult to grind the weld bead on surface grinder so it was necessary to grind the weld bead and make the plates in level.

Mild steel plate of 10mm thickness, 200mm length and 500mm width was mounted on the welding table with the help of C-clamps. Before welding and grinding all 4 bolts were tightened firmly.

Fig4.3:- **The fixture**

While using this fixture one should keep in mind that all the bolts are tightened simultaneously otherwise the plates may get tilted due to more pressure on specific ends. One should also keep in mind that weld spatter may get stick to the surface of plates so spatter must be removed before tightening the bolts.

4.4 Motor Driven Trolly:- The figure shown below is of motor driven trolly to which the welding torch is attached and thorough which speed can be regulated. This trolly can move in both forward and backward direction for welding on rails. This is a separate arrangement from the welding machine to control nozzle to plate distance and speed of welding . It has provision to fix welding torch not only for GMAW but also for TIG and other torch assisted welding.

Fig4.4:- Motor Driven Trolly

CHAPTER-5

DESIGN OF EXPERIMENT

5.1 Introduction

It is highly essential to design an experiment to determine the effects of variable and welding parameter on the various welding responses on a sound basis rather than a commonly employed trial and error basis in conjunction with a small number of repeat experiments for confirmation of results. Apart from the trial and error method of investigation the following techniques are commonly employed by researches.

- Theoretical approach
- Qualitative approach
- Qualitative cum dimensional analysis method
- General quantitative approach

5.2 General Quantitative approach

This method is most commonly used to design the experiments for welding research to predict the effects of welding input parameters on the output parameters or responses. Bases on the result of the factorial designed experiments, regression equations are established using the method of least squares. The correlation co-efficient is a number between +1 and -1 with the intermediate value of zero indicating the absence of correlation but it does not mean that variations are also independent. The limiting value of correlation co-efficient indicates perfect positive or negative correlation. The F-ratio is measure of scatter of the observed values about a predicted curve and it lies between zero and infinity. The larger the value of F the lesser the scatter so in general this approach helps in minimizing the cost and time of testing and of the same time increase the chance of success. However this F ratio of calculated model must be less than the tabulated values at given degrees of freedom in order to be significant .

It is evident from the comparison of various research techniques that the general quantitative approach is based on a more sound logic than any other approach for the generalization of research data. Thus it was decided to make the approach, the basis of designing the experiments. There are various techniques available from the statistical theory of experimental design, which are well suited to engineering investigations. One such technique is a two level factorial design for studying the effects of parameters of responses, and this is one, which is selected for experiments.

5.3 Factorial Design[36,40]:-Factorial design is a standard statistical tool to investigate the effects of number of parameters on the response or output parameter. The most important advantage of this design is that the numbers of parameters are simultaneously studies for a more complete insight into the combined effects of the parameters on the response. In addition to that the interaction between two or more parameters can also be evaluated which is not possible with the conventional approach. Since in that approach all parameters, other than one investigated are held constant.

The experimental plan is to first choose fixed number of level for each of the parameters believed to affect the system under study. The simplest and most economical factorial design is to use two levels for each parameter. With each parameter at two levels, the full factorial design consists of 2^k runs at all possible combinations of testing condition, where k is the number of variables. The number of runs required by a full 2^k factorial design increases geometrically as k is increased and the large increase in the number of trials called for is primarily to provide for estimates of increasing number of higher order interactions which most likely do not exist. Therefore experiments for such estimates would be wasted, increasing cost and time of experimentation. Under such conditions it is possible and advantageous to use only part of the full factorial design i.e., fractional factorial design. In the fractional factorial designed experiment, the main effect of the factors are mixed (confounded) with the effects of higher order interactions. Since, these higher order interaction effects are assumed to be small and thus neglected. Here only three variables are taken due to Lab Constraints, since number of variables are less so full factorial design was selected. Here number of trial is $2^k = 2^3 = 8$, where k= number of controllable variable.

5.4 Plan of investigation :-In order to achieve the desired aim, the investigations were planned to be carried out in the following steps:

- Identifying the welding variables.
- Selection of the useful limits of the welding parameters.
- Developing the design matrix.
- Conducting the experiment as per design matrix.
- Development of mathematical models.
- Evaluation of co-efficient of equations.
- Checking adequacy of the models.
- Testing the significance of regression co-efficient and arriving at the final form of the mathematical models.
- Presenting the main effects and the significant interaction between different parameters in graphical forms.
- Analysis of results and conclusions

5.4.1 Identifying the welding variables:- The welding variables were identified to develop mathematical models to predict individual and combined effects of the parameters. The various parameters selected were:

- Arc voltage(v)
- Wire feed rate(w)
- Welding speed (s)

A two level, full factorial design of eight (2^3) runs was selected and the effects of all the three variables were investigated simultaneously on ultimate tensile strength,yield strength , % elongation, notch tensile strength and impact strength through izod test.

5.4.2Selection of process parameters and their limits

The limits of the welding parameters were selected on the basis of excessive trial runs. The basis of selection of the given range for various welding parameters was that the resultant weld should have good bead appearance, configurations and be free from the visual defects. From the trials following observations were made:-

1. If wire feed rate (current) (w) < 2.5 m/min incomplete penetration was observed. If wire feed rate >3.7m/min overheating, undercuts were observed.The corresponding current range was 100amp to 160amp

2. If arc voltage (v) < 21V,and V> 25 volts too much of weld spatter was observed and bead appearence was also not good.Bead also became flatter on increasing voltage .

3. If welding speed(S) was too low i.e S < 26cm/min the welding wire very frequently got stuck and got welded to the base metal however whenspeed was too highi.e S>45cm/min the bead width was too low it was not even sufficient to fill the v-groove of edge prepared base metal.

The two levels selected for each of the three variables are shown in table 5.1.

Table 5.1: Welding parameters and their limits

Parameters	**Notations**	**Units**	**Level**	
			Low (-1)	**High (+1)**
Arc voltage	V	Volts	21	25
Wire feed rate	W	m/min	2.5	3.7
Welding speed	S	cm/min	26	45

The nozzle to plate distance,gas flow rate ,type of shielding gas, filler wire diameter and filler wire type and all other parameters were held constant through out the experiment . the value of these parameters are listed below in Table 5.2.

Table 5.2:- parameters held constant through out the experiment.

Parameters held constant	Values (units)
Nozzle to plate distance	2.0 cm
Filler wire dia	1.2 mm
Filler wire type(code)	ER70S6
Shieding gas used	CO_2
Gas flow rate(approx.)	10.0 lit/min
Polarity	DCEP

For the convenience of recording and processing the experimental data, the upper and lower levels of the variables were coded as +1 and -1, respectively and the coded values of any intermediate levels can be calculated by using the expression,

$$X_i = \frac{X - \frac{(X_{max} + X_{min})}{2}}{\frac{(X_{max} - X_{min})}{2}}$$

Where X_i = required coded value of a variable

X = any value of the variable from Xmax to Xmin

Xmax = upper level of the variable

Xmin = lower level of the variable

i = number of parameter

5.4.3Developing the design matrix[10]

Factorial design can be represented in the form of design matrix where column and row correspond to levels of factors and the different experimental runs respectively. The sign of column of design matrix were selected in such a way that these are having certain necessary optimal properties, which are given below:

5.4.3.a Symmetry related to the centre of the experiment

The algebraic sum of the elements of the column vector of each parameter should be equal to zero, or

$$\sum_{i=1}^{N} X_{ij} = 0$$

Where,

i = number of factors

N = number of trials, j=1, 2.....k

5.4.3.b Normalisation

The sum of the squares of the elements of each column should be equal to number of trials, or

$$\sum_{i=1}^{N} X_{ij}^{2} \quad = N$$

5.4.3.c Orthogonality

The sum of the term by term product of any column vectors of a matrix should be equal to zero.

$$\sum_{i=1}^{N} X_{ij}\, X_{ui} = 0, j/u\,, u = 0,1,2, \ldots, k$$

5.4.3.d Rotability

The points in a design matrix should be so selected that the precision of predicting the values of the optimization parameters is same at equal distances from the centres of the experiment and does not depend on the direction. The experimental conditions for 2^3 i.e. designs were given in table.

Table 5.3:-Design Matrix based on full factorial [10,40]

Serial no.	V	W	S
1	-1	-1	-1
2	+1	-1	-1
3	-1	+1	-1
4	+1	+1	-1
5	-1	-1	+1
6	+1	-1	+1
7	-1	+1	+1
8	+1	+1	+1

Salient features of Design Matrix table are:

- Trials indicate the sequence number of run under consideration.
- $\mathbf{b_0}$ represents the mean parameter of the experiment.
- $\mathbf{b_1}$, $\mathbf{b_2}$ **and** $\mathbf{b_3}$, represent the notation used for controlled variables in the order of arc voltage, wire feed rate and welding speed respectively.
- The signs +1 and -1 as already indicated refer to the upper and lower levels of that parameter under which they are recorded.
- $\mathbf{b_{12}}$, $\mathbf{b_{13}}$ **and** $\mathbf{b_{23}}$ represent the notation used for the coefficients of interaction effect between wire feed rate,arc voltage and welding speed.

5.4.4Developing Design Matrix for Calculating the Coefficient

Table 5.4:- Design Matrix for calculating coefficients (full factorial)

S.No.	b_0	b_1	b_2	b_3	b_{12}	b_{13}	b_{23}
		v	w	s	vw	vs	ws
1.	+	-1	-1	-1	+1	+1	+1
2.	+	+1	-1	-1	-1	-1	+1
3.	+	-1	+1	-1	-1	+1	-1
4.	+	+1	+1	-1	+1	-1	-1
5.	+	-1	-1	+1	+1	-1	-1
6.	+	+1	-1	+1	-1	+1	-1
7.	+	-1	+1	+1	-1	-1	+1
8.	+	+1	+1	+1	+1	+1	+1

$$Y= b_0+b_1V+b_2W+b_3S+b_{12}VW+b_{13}VS+b_{23}WS$$

5.4.5Conducting Experiments as per the design matrix

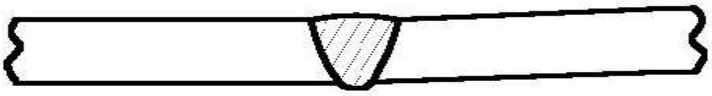
PROCESSES INVOLVED:

The following procedure was adopted while carrying out the experimentation in the welding lab:

1. **Cutting mild steel strip:-**The base metal sheets of dimensions 80mm x 50mm x 6mm were cut on power hacksaw machine using kerosene as a cutting fluid.
2. **Job preparation:-**As the thickness of the plates is 6mm a double V groove butt joint of 60^o groove angle is required. Edge preparation is done on surface grinding machine with the help of angle vice which is shown in the fig 5.1.

Fig 5.1:- Angle vice

The pieces were clamped on angle vice and this vice was mounted on surface grinder in order to prepare double V groove of 60^0 .A double V groove was chosen because by earlier experience it was found that it is necessary to ensure proper penetration and sound weld. One major reason to choose double v groove was that it can prevent weld distortion as both sides have weld bead and the distortion on upper side is balanced by the lower one. As illustrated by the figures given below .



Angular distortion in single vee butt

Double vee better than single vee

Single u better than single vee

Fig 5.2:- Edge preparation before welding [9]

V- angle was kept to 60^0 because if it was kept at 90^0 the top portion of the V was left unfilled in some cases as the bead width is less during high speed and low current and if it was kept 45^0 then it will be too short to assist good weld. The depth of the groove was 3 mm .Then these pieces were clamped on specially designed fixture and welding was done with in the given maximum and minimum range of arc voltage, wire feed rate and welding speed, as per the design matrix. The following pictures were taken during welding process . The fixture not only helped in arresting the little possible weld distortion but also helped to avoid making tech weld. These welded plates were then allowed to cool slowly at room temperature in air.

Fig 5.3(A):-welding in progress

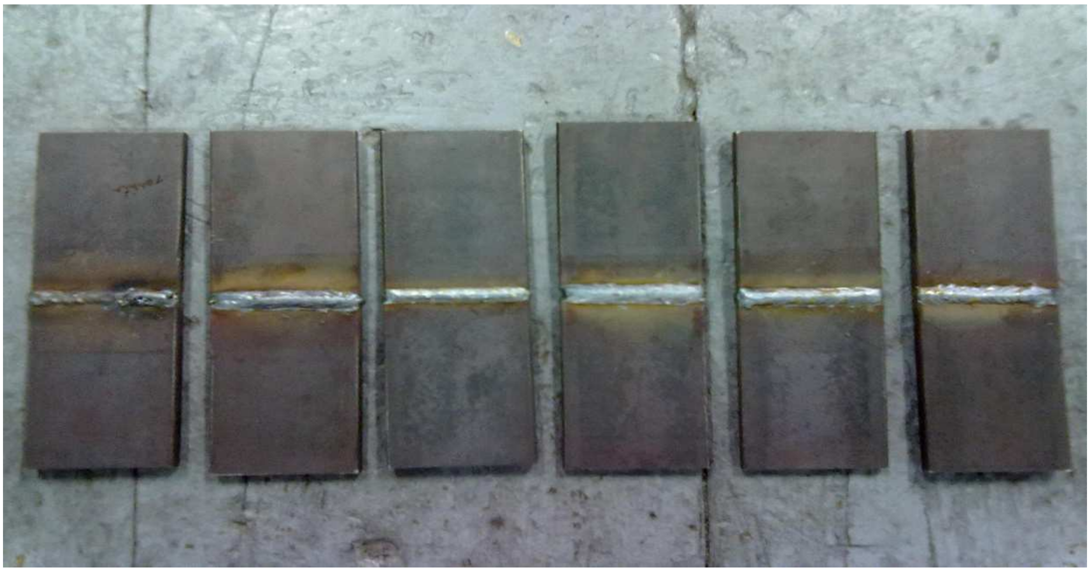


Fig 5.3(b):- Some of the welded plates

After the welding of all plates these were mounted on surface grinding machine to remove the weld bead reinforcement so that the tensile specimens are in perfect shape and dimension.

Again the specially designed fixture was used to grind the bead as both sides have bead and the magnetic surface is not able to catch the welded plates due to non flat surface . The picture below shows how it was done.

Fig 5.4:- Grinding in progress

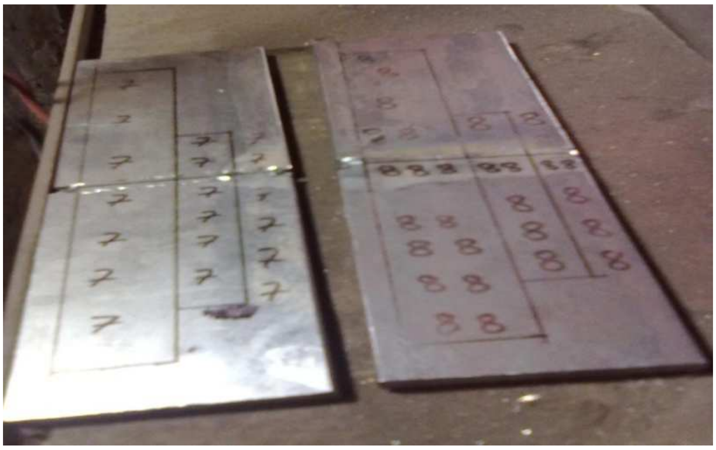
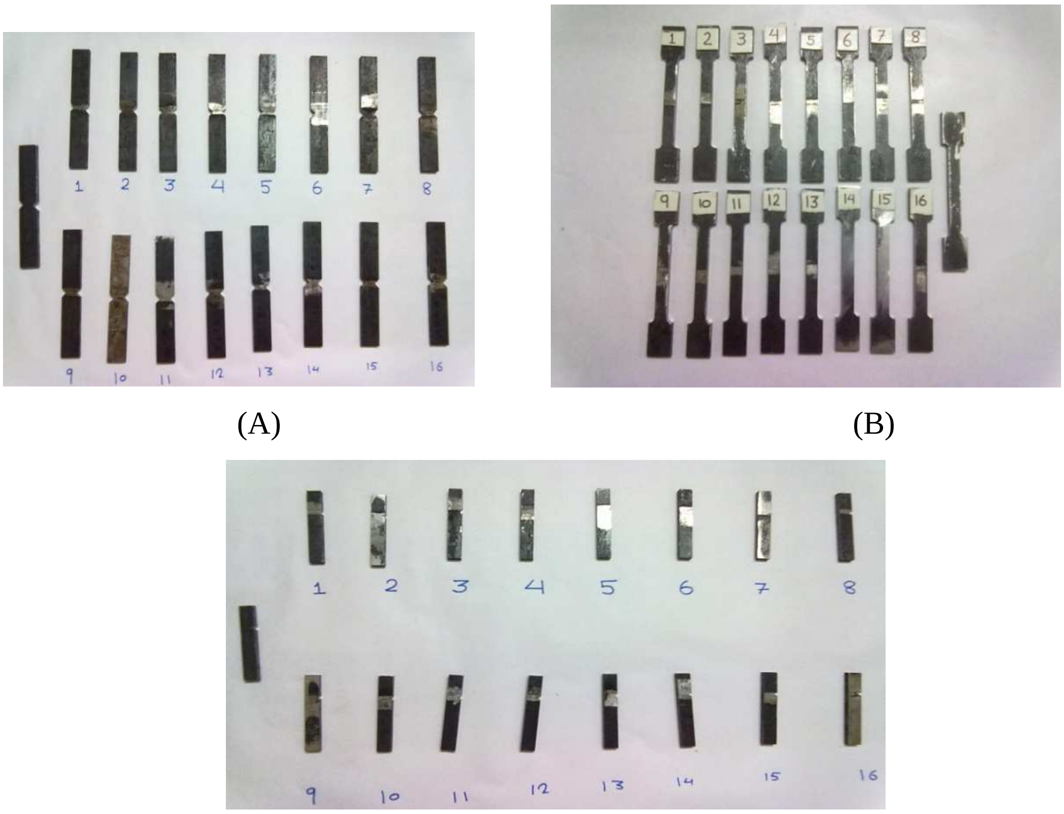


Fig 5.5:- Marking the specimens

These plates were then cut on surface grinding machine by parting wheel. The rectangular specimens thus obtained were mounted on milling machine to get required dimensions. The notches were made on the shaper with notch radius less than 0.4mm. The following figure shows the sub size specimens which were prepared according to ASTM E8M-04 and ASTM E23-04.



(A) (B)

(C)

Fig5.6:-The notch tensile specimen(A),the tensile specimen(B) and Izod specimen(C)

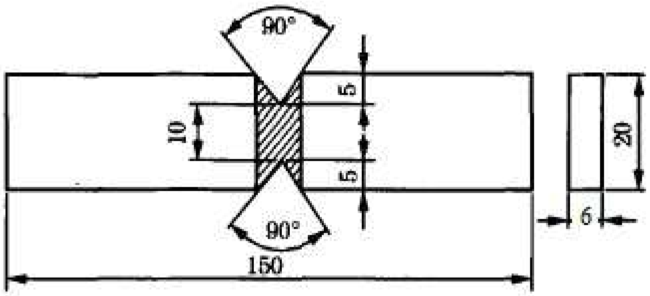


Fig5.7:- Notch tensile specimen

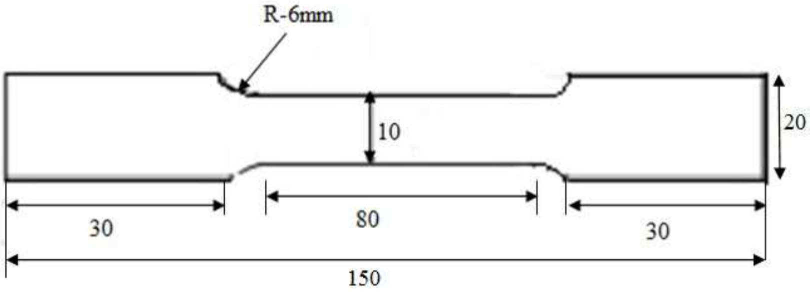


Fig 5.8:- Tensile test specimen

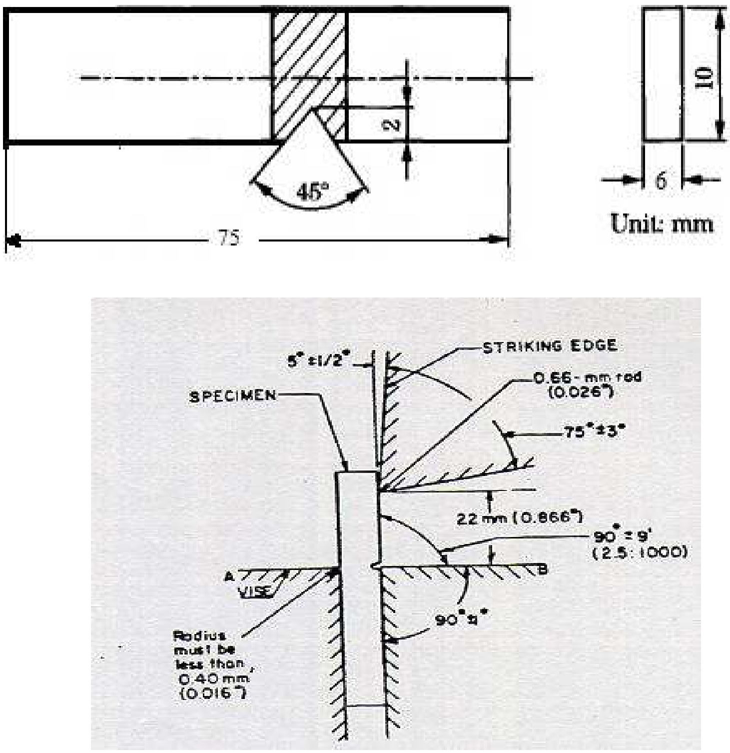
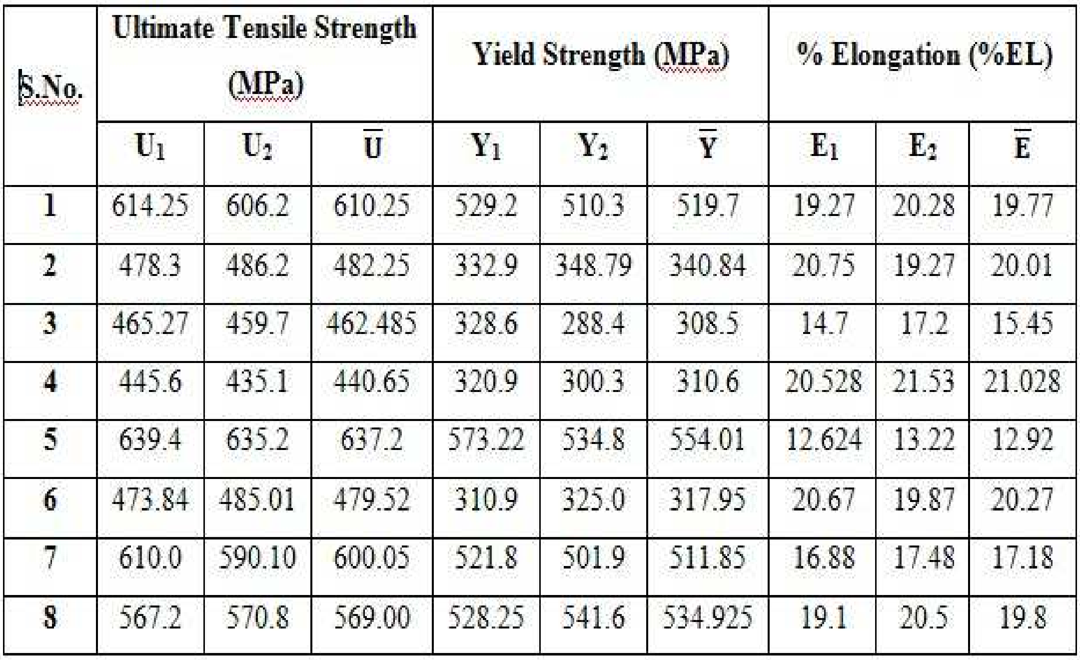


Fig 5.9:- Izod test specimen(above) and position of strike of hammer[1]

3. **Tensile Testing-** Tensile test is then carried out on computer controlled UTM machine with a cross head speed of 2mm/min. The maximum capacity of this machine was 50KN. However the notch tensile test was conducted on a Hydraulic mechanical UTM machine of 400KN capacity due to some limitations of computerised UTM machine.

Fig 5.10:- UTM machine

Table 5.5:- Response table for tensile test



S.No.	Ultimate Tensile Strength (MPa)			Yield Strength (MPa)			% Elongation (%EL)		
	U_1	U_2	$\bar{U}$	Y_1	Y_2	$\bar{Y}$	E_1	E_2	$\bar{E}$
1	614.25	606.2	610.25	529.2	510.3	519.7	19.27	20.28	19.77
2	478.3	486.2	482.25	332.9	348.79	340.84	20.75	19.27	20.01
3	465.27	459.7	462.485	328.6	288.4	308.5	14.7	17.2	15.45
4	445.6	435.1	440.65	320.9	300.3	310.6	20.528	21.53	21.028
5	639.4	635.2	637.2	573.22	534.8	554.01	12.624	13.22	12.92
6	473.84	485.01	479.52	310.9	325.0	317.95	20.67	19.87	20.27
7	610.0	590.10	600.05	521.8	501.9	511.85	16.88	17.48	17.18
8	567.2	570.8	569.00	528.25	541.6	534.925	19.1	20.5	19.8

Table 5.6:- response table for notch tensile strength

S.No.	Notch Tensile Strength (MPa)		
	N_1	N_2	$\overline{N}$
1	648	636	642
2	521	539	530
3	518	502	510
4	488	472	480
5	682	658	670
6	511	529	520
7	640	630	645
8	600	615	607.5

Fig5.11 :- Izod impact testing machine

This machine gave the readings in foot pound so in order to convert it into SI unit of joules it should be multiplied by a factor of 1.3558 as **1ft.lb=1.3558 joules.**

Table 5.7:- Response table for Izod impact test

S.No.	Izod impact strength (joules)		
	I_1	I_2	$\bar{I}$
1	79.40	72.42	75.91
2	68.00	73.00	70.50
3	69.90	65.70	68.8
4	56.24	52.23	54.23
5	86.05	76.65	82.348
6	59.51	64.51	62.01
7	71.94	66.34	69.14
8	62.98	67.18	65.08

.Table 5.8:- comparison of ultimate tensile strength of notched and un-notched specimen

S.No.	Notch strength ratio		
	$\bar{N}$	$\bar{U}$	N.S.R $(\bar{N}/\bar{U})$
1	642	610.25	1.052
2	530	482.25	1.099
3	510	462.485	1.103
4	480	440.65	1.089
5	670	637.2	1.051
6	520	479.52	1.084
7	645	600.05	1.074
8	607.5	569.00	1.067

Table 5.9:- Overall response table for average values

S.no	V	W	S	U.T.S	Y.S	%E	N.T.S	Impact strength
1	-1	-1	-1	610.25	519.7	19.77	642	75.91
2	+1	-1	-1	482.25	340.84	20.01	530	70.50
3	-1	+1	-1	462.485	308.5	15.45	510	68.8
4	+1	+1	-1	440.65	310.6	21.028	480	54.23
5	-1	-1	+1	637.2	554.01	12.92	670	82.348
6	+1	-1	+1	479.52	317.95	20.27	520	62.01
7	-1	+1	+1	600.05	511.85	17.18	645	69.14
8	+1	+1	+1	569.00	534.925	19.8	607.5	65.08

CHAPTER-6

MATHEMATICAL MODELLING

6.1 Introduction

Mathematical models were developed for predicting the effect of process parameters on tensile strength; yield strength, % elongation, impact strength and notch tensile strength of GMAW welded mild steel using full factorial technique. The coefficients of models were determined with the help of a software MINITAB which used method of least squares. The adequacy and the significance of the coefficients of the models were tested by the analysis of variance (ANOVA) technique and ‘t’ test respectively.

6.2 Development of a mathematical model

The response function can be expressed as:

$$\mathbf{Y = f\,(V,W,S)}$$

Where, Y= response parameter

V = arc voltage

W = wire feed rate

S = welding speed

The effects caused by changes in the three main process parameters and their interactions can be expresses as:

$$\mathbf{Y = b_0 + b_1V + b_2W + b_3S + b_{12}VW + b_{13}VS + b_{23}WS}$$

Where b_0, is constant and b_1, b_2, b_3, b_{12}, b_{13}, b_{23} are co-efficient of the model. These coefficients as calculated are listed in table given below for all the five responses viz tensile strength; yield strength, % elongation, impact strength and notch tensile strength.[37]

6.3 Evaluation of the co-efficient of the model:- The values of the co efficient of the response were calculated using regression analysis. The calculations were carried out using MINITAB and the values of the coefficient are listed below.

Table 6.1:- coefficients of the models

S.No.	**coefficients**	**U.T.S**	**Y.S**	**%E**	**N.T.S**	**Impact strength**
1	**b_0**	535	425	18.4	578	68.1
2	**b_1**	-42.4	-48.7	2.1	-40.3	-5.42
3	**b_2**	-17.2	-8.33	0.186	-12.8	-4.06
4	**b_3**	36.3	54.9	-0.835	37.5	4.02
5	**b_{12}**	29.1	55	0.202	25.2	1.02
6	**b_{13}**	-4.85	-4.5	.844	-4.75	-0.68
7	**b_{23}**	30.2	52	1.01	32.7	2.34

6.4 Adequacy of the model

The analysis of variance (ANOVA) technique was used to check the adequacy of the developed models. As per this technique,

(a) The F-ratio of the developed model was calculated and compared with the standard tabulated value of F-ratio for a specific level of confidence(95%,$\alpha = .05$) .

(b) If calculated value of F-ratio does not exceed the tabulated value(upper critical value), then with the corresponding confidence probability the model may be considered adequate [23]. As shown in figure 6.1.F_u is Upper critical value of F ratio.

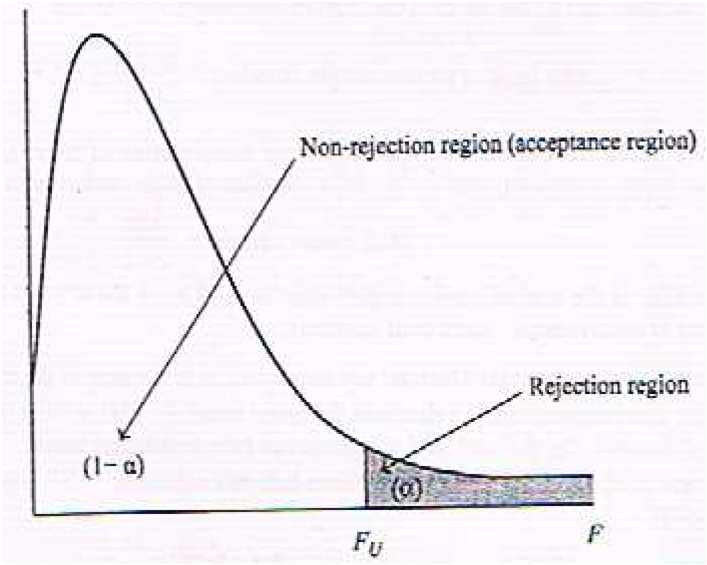


Fig6.1:-Rejection and acceptance region when using ANOVA [41]

For this purpose, the F-ratio of the model is defined as the ratio of variance adequacy, also known as residual variance (S^2ad) to the variance of reproducibility, also known as variance of optimization parameter ($S^2{}_y$). Therefore:

$$F_{\text{model}} = \frac{S_{\text{ad}}^2}{S_y^2}$$

Here

$$S_{\text{ad}}^2 = \sum_{i=1}^{N}(Y_i - \overset{\wedge}{Y_i})^2 / DF$$

Where, N = Number of trials

Y_i = third observed value of the response

$\overset{\wedge}{Y_i}$ = Predicted / Estimated value of response

DF = Degree of freedom = [N – (K +1)], Where K = Number of independently controllable variables

Where K= Number of independently controllable variables.

$$S_y^2 = 2\sum_{i=1}^{N}(Y_{iq} - Y_i)^2/N$$

Where

Y_{iq} = One of the observed value of the two responses

Y_i = Average value of the two response

N = No. of trials

6.5 Significance of the coefficients

The values of the regression co-efficient give an idea as to what extent the control variables affect the responses quantitatively. It is evident that those of the co-efficient, which are not significant, can be eliminated, along with the responses with which they are associated, without sacrificing much of accuracy, thereby reducing the mathematical labor. To enable this, the student’s t test is used. As per this test,

a) The calculated value of t corresponding to a coefficient is compared with the standard tabulated value of specific level of probability. Here the standard tabulated value of t is 2.3 at 8, 0.05.

b) If the calculated value of t exceeds the tabulated one, then with the corresponding confidence probability the co-efficient is said to be significant.

For this purpose the value of t is given by

$$t = \frac{|b_j|}{S_{bj}}$$

Where $|bj|$ represents the absolute value of co-efficient whose significance is being tested, and S_{bj} the standard deviation of co-efficient given by

$$S_{bj} = \sqrt{\frac{\text{Variance of optimization parameter } (S_y^2)}{\text{Number of trials } (N)}} = \sqrt{\frac{S_y^2}{N}}$$

The calculation of $S^2{}_y$, $S^2{}_{ad}$ and S_{bj} are shown in separate Tables for each response.

When the significant co-efficient are known, the model is redeveloped by using these values. The model so developed is utilized to determine the values of response parameter for each given set of welding variables and the data so produced are represented graphically.

6.6 Calculation of variance of optimization parameters (S^2y)

Table 6.2:- Variance of optimization for ultimate tensile strength

S.No.	U_1	U_2	$\overline{U}=(U_1+U_2)/2$	$\overline{U}-U_2$	$(\overline{U}-U_2)^2$
1	614.25	606.2	610.25	4.05	16.4025
2	478.3	486.2	482.25	-3.95	15.6025
3	465.27	459.7	462.485	2.785	7.7560
4	445.6	435.1	440.65	5.55	30.8025
5	639.4	635.2	637.2	2.01	4.0401
6	473.84	485.01	479.52	-5.49	30.1401
7	610.0	590.10	600.05	9.95	99.002
8	567.2	570.8	569.00	-1.8	3.24
				$\sum(\overline{U}-U_2)^2$	**206.98**
				S^2y	**51.745**

Table 6.3:- Variance of optimization for yield strength

S.No.	YS_1	YS_2	$\overline{YS}=(YS_1+YS_2)/2$	$\overline{YS}-YS_2$	$(\overline{YS}-YS_2)^2$
1	529.2	510.3	519.7	9.4	88.36
2	332.9	348.79	340.84	-7.94	63.04
3	328.6	288.4	308.5	20.1	404.01
4	320.9	300.3	310.6	10.3	106.09
5	573.22	534.8	554.01	19.21	369.02
6	310.9	325.0	317.95	-7.05	49.70
7	521.8	501.9	511.85	9.95	99.00
8	528.25	541.6	534.925	-6.675	44.55
				$\sum(\overline{YS}-YS_2)^2$	**1223.78**
				S^2y	**305.8**

Table 6.4: Variance of optimization for % Elongation

S.No.	E_1	E_2	$\overline{E}=(E_1+E_2)/2$	$\overline{E}-E_2$	$(\overline{E}-E_2)^2$
1	19.27	20.28	19.77	-0.5	.25
2	20.75	19.27	20.01	0.25	.063
3	14.7	17.2	15.45	-1.75	3.06
4	20.528	21.53	21.028	-.502	.252
5	12.624	13.22	12.92	-0.3	.09
6	20.67	19.87	20.27	0.4	.16
7	16.88	17.48	17.18	-0.3	.09
8	19.1	20.5	19.8	-0.7	.49
				$\sum(\overline{E}-E_2)^2$	**4.452**
				S^2y	**1.113**

Table 6.5: Variance of optimization for Notch tensile strength

S.No.	N_1	N_2	$\bar{N}$	$\bar{N}$- N_2	$(\bar{N}$- $N_2)^2$
1	648	636	642	6	36
2	521	539	530	-9	81
3	518	502	510	8	64
4	488	472	480	8	64
5	682	658	670	12	144
6	511	529	520	-9	81
7	640	630	645	+15	225
8	600	615	607.5	-7.5	56.25
				$\sum(\bar{N} - \mathbf{N2})^2$	**751.25**
				S^2y	**187.81**

Table 6.6: Variance of optimization for impact strength

S.No.	I_1	I_2	$\bar{I}$	$\bar{I}$-I_2	$(\bar{I}$-$I_2)^2$
1	79.40	72.42	75.91	3.488	12.166
2	68.00	73.00	70.50	-2.5	6.25
3	69.90	65.70	68.8	3.1	9.61
4	56.24	52.23	54.23	2.0	4.0
5	86.05	76.65	82.348	5.7	32.49
6	59.51	64.51	62.01	-2.5	6.25
7	71.94	66.34	69.14	2.81	7.8961
8	62.98	67.18	65.08	-2.1	4.41
				$\sum(\bar{I} - \mathbf{I2})^2$	**83.072**
				S^2y	**20.768**

6.7 Calculation of variance of adequacy factor (S^2ad)

Table 6.7: Variance of adequacy for ultimate tensile strength

S. No.	**U_{obsd}**	**U_{est}**	**$\Delta U = (U_{obs} - U_{est})$**	**ΔU^2**
1	610.25	612.7	-2.45	6.01
2	482.25	469.75	12.5	156.25
3	462.485	459.75	2.735	7.48
4	440.65	442.85	-2.85	8.12
5	637.2	634.66	2.55	6.50
6	479.52	482.8	-3.28	10.76
7	600.05	602.45	-2.4	5.76
8	569.00	566.15	2.85	8.12
			$\sum \Delta U^2$	**208.99**
			S^2ad	**52.33**

Table 6.8: Variance of adequacy for yield strength

S. No.	**YS_{obsd}**	**YS_{est}**	**$YS = (YS_{obst} - Ys_{est}$**	**ΔYS^2**
1	519.7	529.61	-9.91	98.208
2	340.84	331.25	9.59	91.968
3	308.5	298.17	10.4	108.16
4	310.6	320.57	-9.97	99.4
5	554.01	543.13	11.01	121.22
6	317.95	329.03	-11.08	122.76
7	511.85	521.77	-9.92	98.40
8	534.925	525.37	9.55	91.20
			$\sum \Delta YS^2$	**831.33**
			S^2ad	**207.85**

Table 6.9: Variance of adequacy for %Elongation

S. No.	E_{obsd}	E_{est}	$\Delta E = (E_{obs} - E_{est})$	ΔE^2
1	19.77	18.605	1.165	1.357
2	20.01	21.113	-1.103	1.216
3	15.45	16.553	-1.11	1.232
4	21.028	19.87	1.158	1.340
5	12.92	14.027	-1.103	1.216
6	20.27	19.11	1.159	1.343
7	17.18	16.015	1.165	1.357
8	19.8	21.907	-1.107	1.225
			$\sum \Delta E^2$	**10.289**
			S^2**ad**	**2.57**

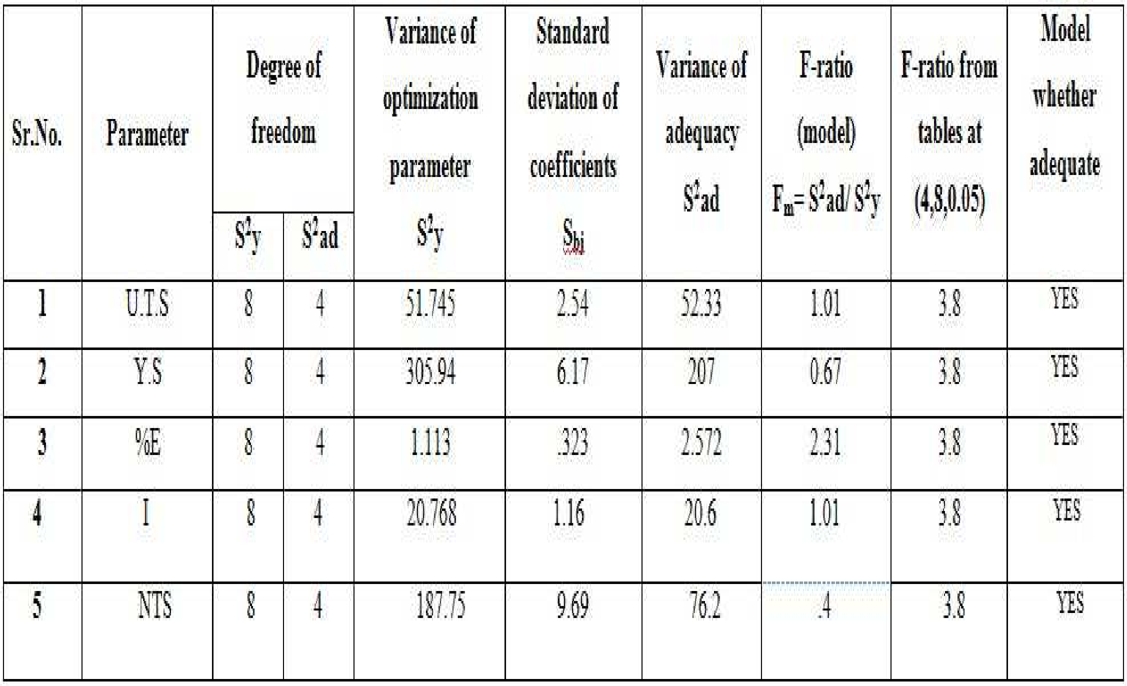
Table 6.10: Variance of adequacy for Notch tensile strength

S. No.	N_{obsd}	N_{est}	$\Delta N = (N_{obs} - N_{est})$	ΔN^2
1	642	646.95	-4.95	24.50
2	530	525.25	4.75	22.56
3	510	506.55	3.45	11.90
4	480	485	-5.00	25
5	670	665.65	4.35	18.92
6	520	525.15	4.85	23.52
7	645	655.8	10.8	116.64
8	607.5	615.35	-7.85	61.62
			$\sum \Delta E^2$	**304.675**
			S^2**ad**	**76.168**

Table 6.11:- Variance of adequacy for Impact strength

S. No.	I_{obsd}	I_{est}	$\Delta I = (I_{obs} - I_{est})$	ΔI^2
1	75.91	78.93	-3.02	9.12
2	70.50	67.51	2.99	8.94
3	68.8	64.71	4.09	16.72
4	54.23	57.27	-3.04	9.24
5	82.348	78.27	4.078	16.63
6	62.01	64.03	-2.02	4.08
7	69.14	72.07	-2.92	8.52
8	65.08	62.01	3.07	9.42
			$\sum \Delta I^2$	**82.69**
			S^2ad	**20.67**

Table 6.12: Analysis of variance



Sr.No.	Parameter	Degree of freedom		Variance of optimization parameter S^2y	Standard deviation of coefficients S_{bi}	Variance of adequacy S^2ad	F-ratio (model) $F_m = S^2ad / S^2y$	F-ratio from tables at (4,8,0.05)	Model whether adequate
		S^2y	S^2ad						
1	U.T.S	8	4	51.745	2.54	52.33	1.01	3.8	YES
2	Y.S	8	4	305.94	6.17	207	0.67	3.8	YES
3	%E	8	4	1.113	.323	2.572	2.31	3.8	YES
4	I	8	4	20.768	1.16	20.6	1.01	3.8	YES
5	NTS	8	4	187.75	9.69	76.2	.4	3.8	YES

6.8 t-test for significant coefficient

Table 6.13: t-values for coefficients of model

S.No.	Coefficient (b_{ij})	t= b_j/S_{bj} (for responses)				
		U.TS	Y.S	%E	I	N.T.S
1	b_o	210.63	68.88	57.5	58.7	59.65
2	b_1	16.7	7.89	6.56	46.72	4.158
3	b_2	6.77	1.35	.58	3.5	1.32
4	b_3	14.29	8.897	2.61	3.46	3.87
5	b_{12}	11.456	8.91	.63	.63	2.6
6	b_{13}	1.9	0.73	2.64	0.87	0.49
7	b_{23}	11.88	8.427	3.156	2.34	3.4

Table 6.14: Significant coefficients after t-test of model

S.No.	coefficients	U.T.S	Y.S	%E	N.T.S	Impact strength
1	b_0	535	425	18.4	578	68.1
2	b_1	-42.4	-48.7	2.1	-40.3	-5.42
3	b_2	-17.2	-	-	-	-4.06
4	b_3	36.3	54.9	-0.835	37.5	4.02
5	b_{12}	29.1	55	-	25.2	-
6	b_{13}	-	-	.844	-	-
7	b_{23}	30.2	52	1.01	32.7	2.34

6.9 Proposed mathematical models

Neglecting the higher order interactions as per t-value of coefficients, the proposed models for predicting mechanical properties are given below. These models give values close to the observed values however some of the coefficients were eliminate in t test so as to reduce the mathematical calculation without affecting much of the accuracy.

a)Ultimate Tensile Strength (UTS):

$$UTS = 535 - 42.4V - 17.2W + 36.3S + 29.1VW + 30.2WS$$

b)Yield Strength (YS):

$$YS = 425 - 48.7V + 54.9S + 55VW + 52WS$$

c)Elongation (%E):

$$\%E = 18.4 + 2.1V - 0.8S + 0.84VS + 1.01WS$$

d)Impact strength(I):-

$$I = 68.1 - 5.42V - 4.06W + 4.04S + 2.34WS$$

e)Notch tensile strength:-

$$N.T.S = 578 - 40.3V + 37.3S + 25.2VW + 32.7WS$$

Chapter-7

RESULTS & DISCUSSION

7.1 Main and interaction effects of process parameters on UTS:-

Ultimate tensile strength (UTS) decreased from 552.3 MPa to 517.97Mpa on going from low level to high level of wire feed rate as shown in fig.7.1. UTS increases from 498.827Mpa to 571.44 Mpa when speed increases from low to high level as shown in fig 7.2. UTS decreases from 577.51 Mpa to 492.756Mpa as voltage increases from low level to high level as shown in fig 7.3. The UTS is directly affected by heat input . It increases with decreases in heat input that is voltage and current increase the heat input while speed decreases the heat input and thus the UTS increases with speed and decreases with increase in a voltage and wire feed rate (current).

The interaction effects are shown in fig. 7.4 and fig 7.5.The two lines for the low level and high level are not parallel which clearly shows that there is interaction effect. Fig7.4 clearly shows that when voltage is minimum UTS decreases from 623.76MPa to 531.26Mpa with increase in wire feed rate however at maximum voltage input UTS increases from 480.837MPa to 504.675MPa. Fig 7.5 shows that UTS slowly increases with the welding speed from 546.23MPa to 558.36MPa when wire feed rate was at minimum. But it increases drastically with speed, from 451.418MPa to 584.53MPa , when wire feed rate was at maximum value.

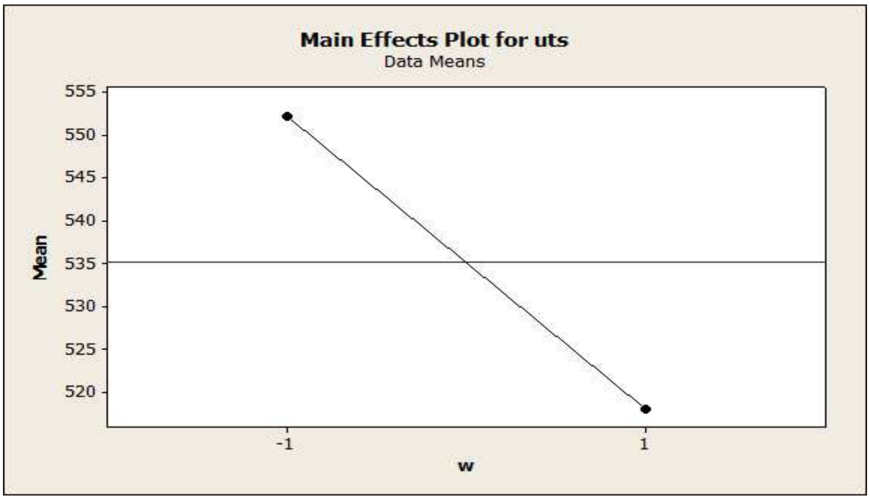


Fig 7.1:- Main effect plot between U.T.S and wire feed rate (W)

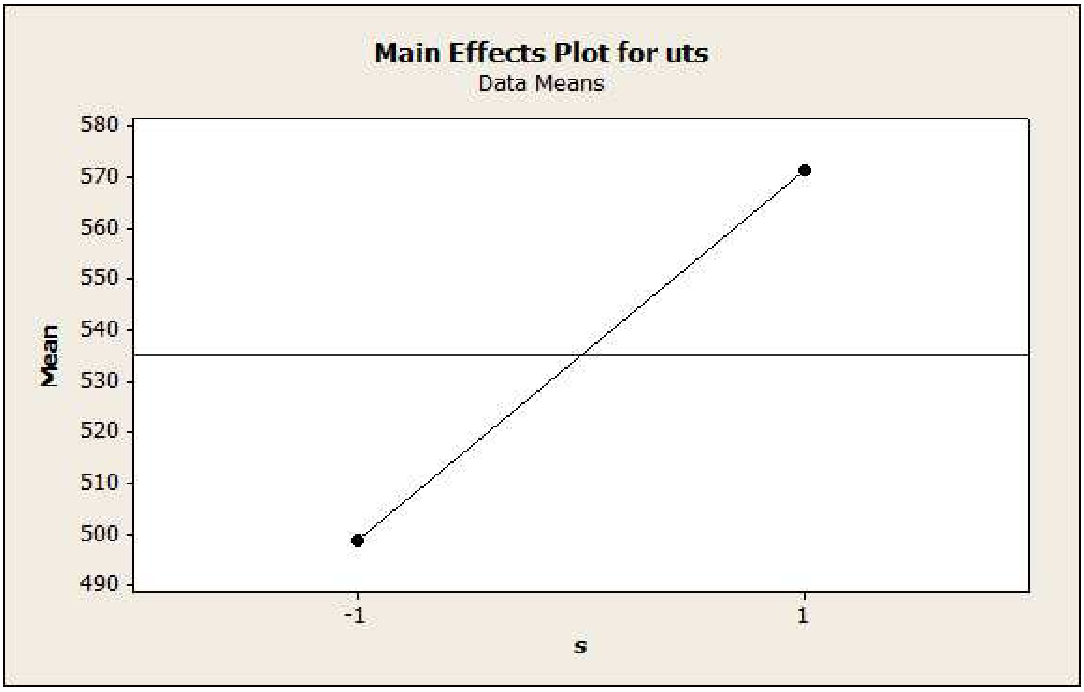


Fig7.2:- Main effects plot between U.T.S and welding speed(S).

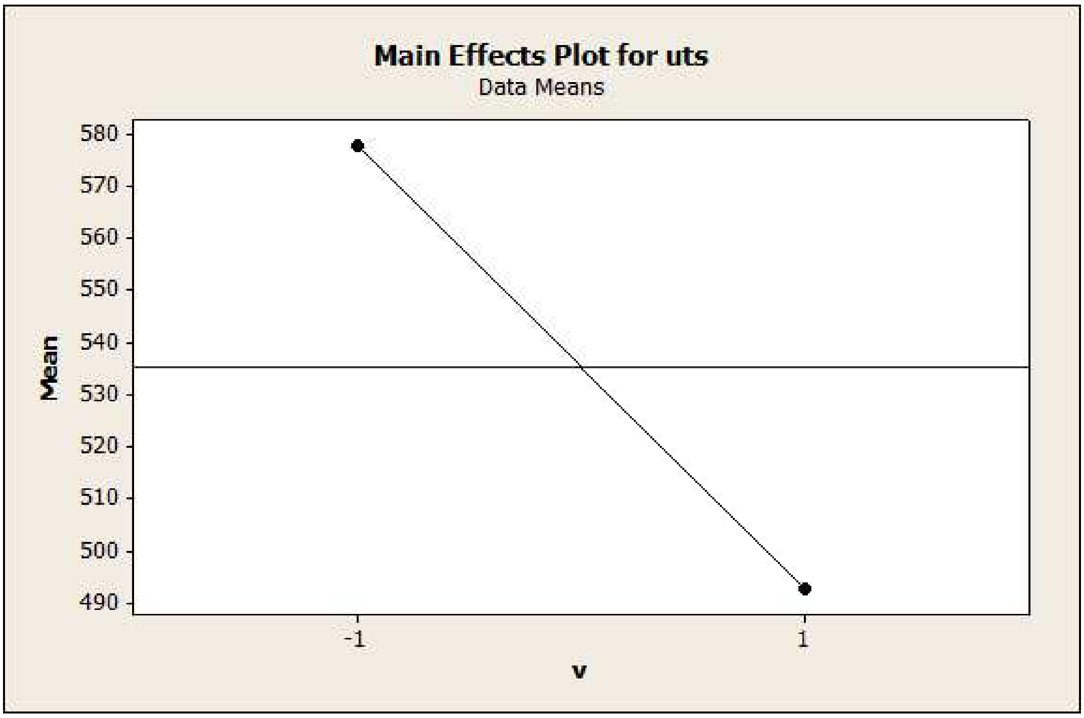


Fig 7.3:- Main effects plot between U.T.S and arc voltage(V)

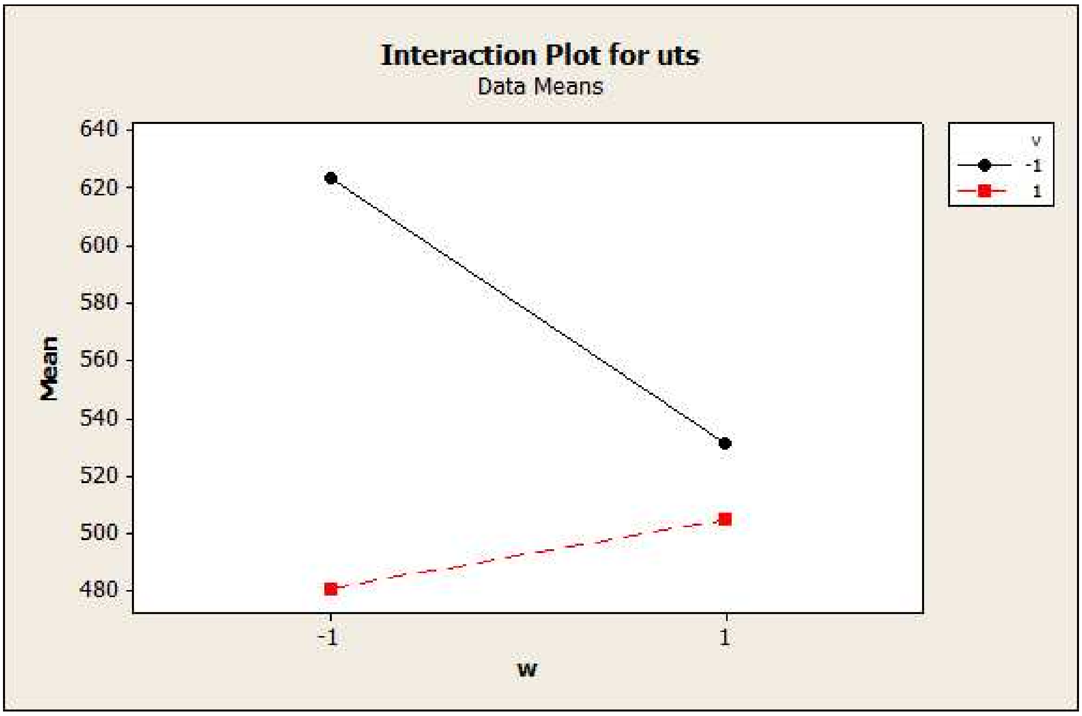


Fig 7.4:-Interaction effects of voltage and wire feed rate on U.T.S

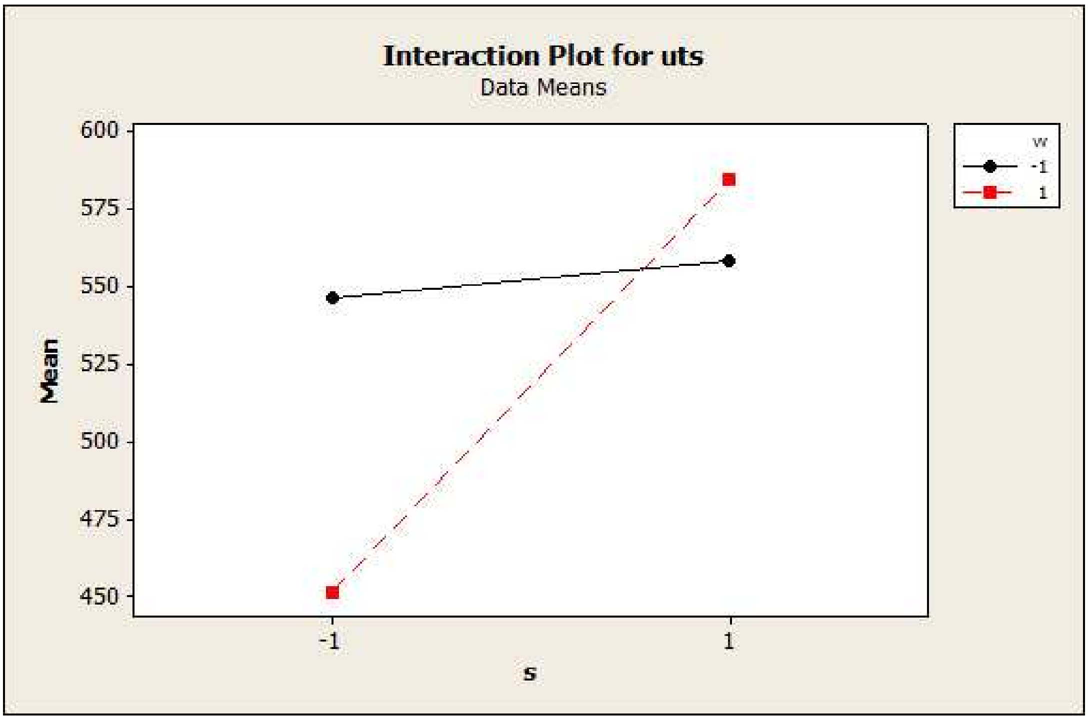


Fig 7.5:-Interaction effects of welding speed and wire feed rate on U.T.S

7.2 Main and interaction effects of process parameters on Y.S:

The yield strength (Y.S) decreased from 473.53MPa to 376.079Mpa on going from low level to high level of arc voltage as shown in fig.7.6. Y.S increases from 369.92Mpa to 479.684 Mpa when speed increases from low level to high level as shown in fig 7.7. Y.S is affected by heat input as heat input increases it decreases as voltage increases heat input increases and thus YS decreases while it increases with increase with speed.

The interaction effects of wire feed rate, arc voltage and welding speed are shown in fig. 7.8 and fig 7.9 .The two lines for the low level and high level are not parallel which clearly shows that there is interaction effect. Two parallel lines in an interaction effect plot show no interaction between the parameters. Fig 7.8 shows that yield strength increases slightly from 430.3MPa to 435.98MPa with welding speed when wire feed rate is minimum while it increases drastically ,from 309.55MPa to 523.4MPa , when wire feed rate is maximum. Fig 7.9 shows that yield strength decreased with increase in wire feed rate , from 536.88MPa to 410MPa, when arc voltage was minimum, however it increased from 329.39MPa to 422.762MPa when voltage was at maximum level.

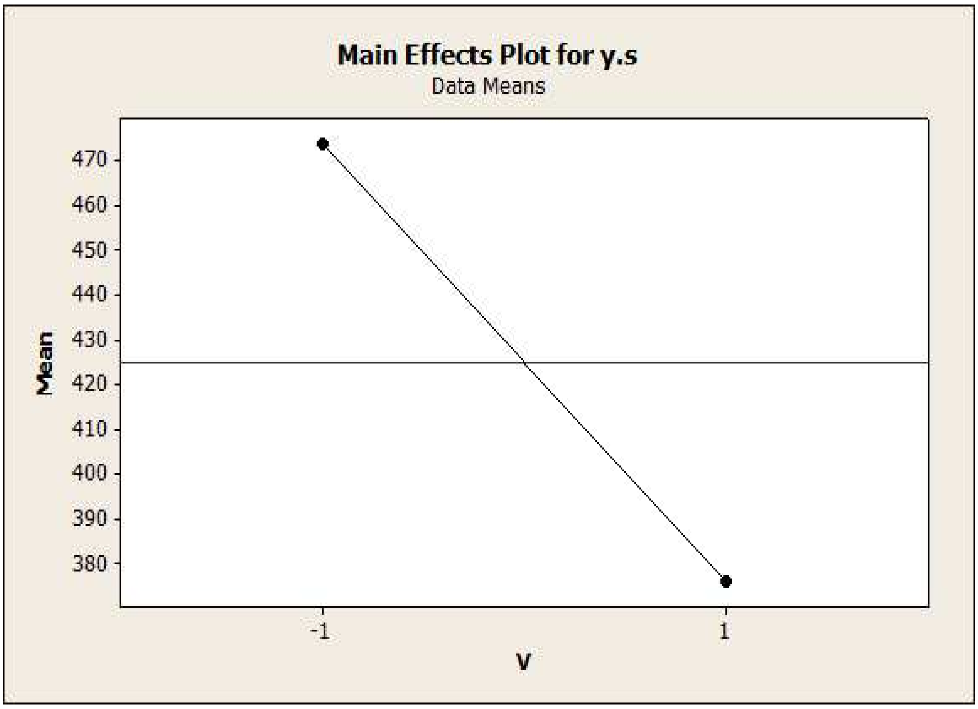


Fig 7.6:-Main effect of arc voltage on Y.S

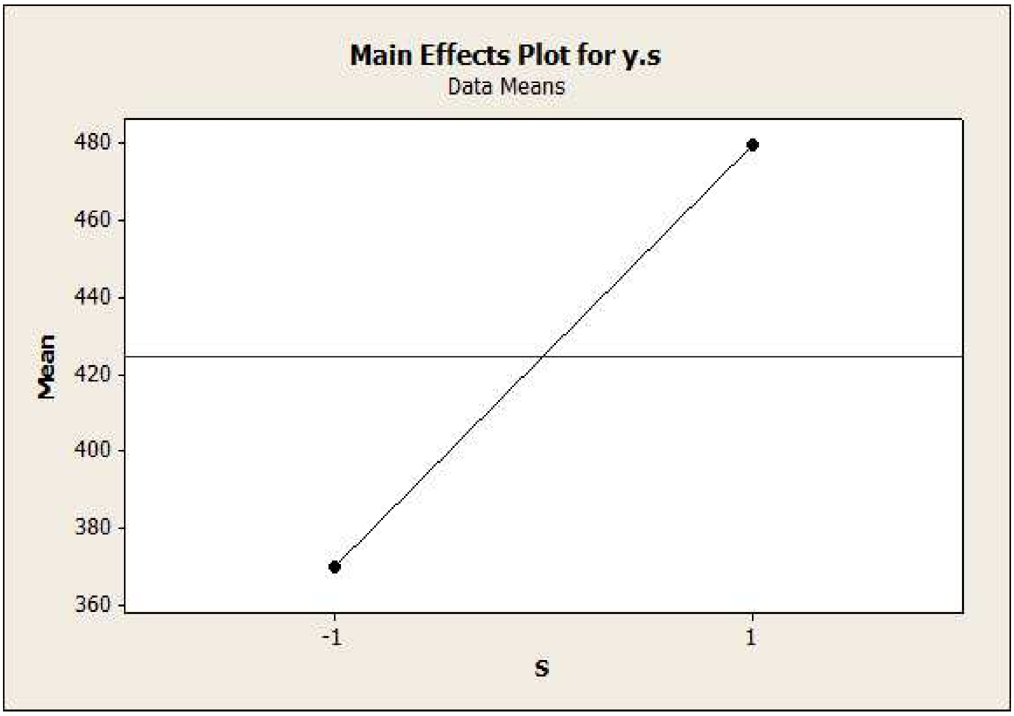


Fig 7.7:-Main effect of welding speed on Y.S

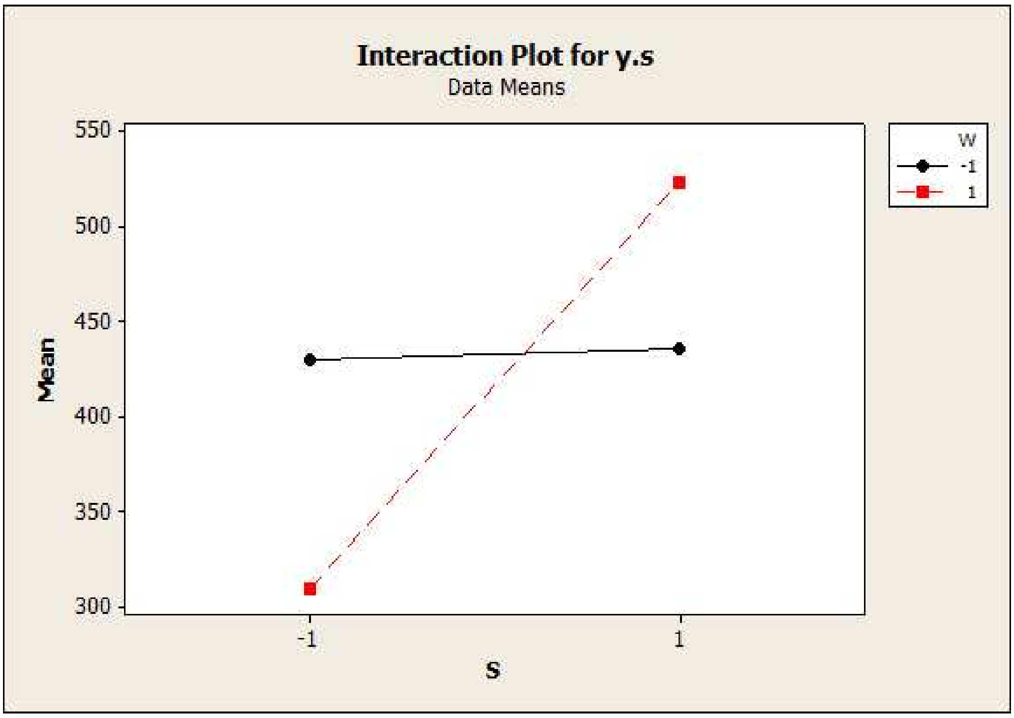


Fig 7.8 Interaction effects of welding speed and wire feed rate on Y.S

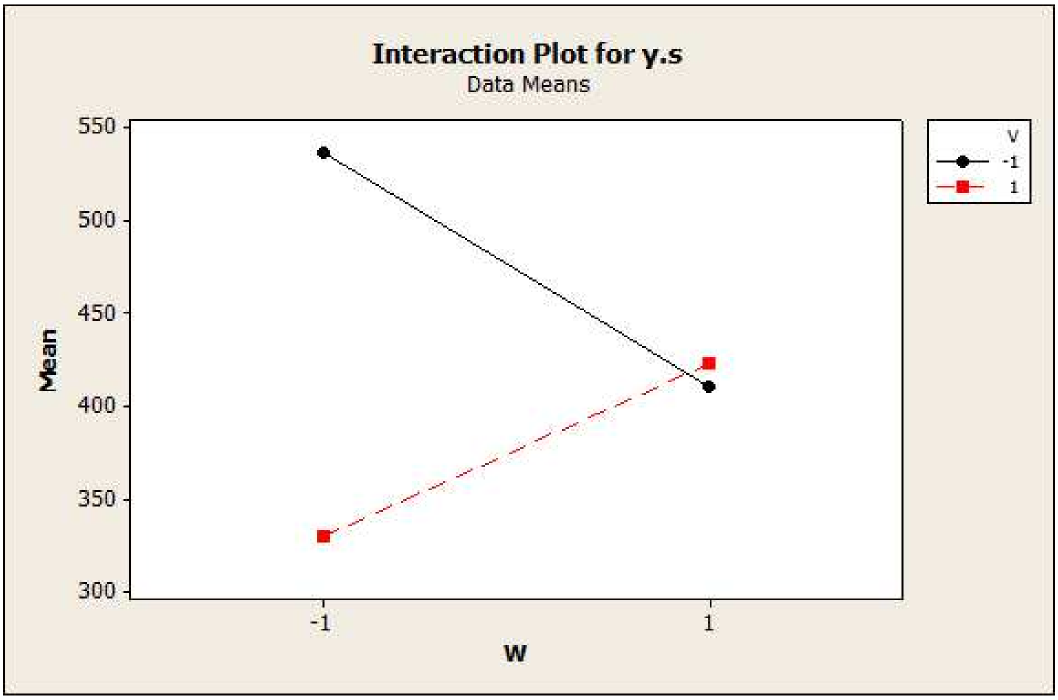


Fig 7.9 Interaction effects of welding speed and wire feed rate on Y.S

7.3 Main and interaction effects of process parameters on % Elongation:-

Unlike the ultimate tensile strength and yield strength , the % elongation of the welded materials increased from 16.331% to 20.53% on going from low level to high level of arc voltage as shown in fig.7.10. % elongation decreases from 19.063% to 17.79 when speed increases from low level to high level as shown in fig 7.11.The reason being that with increase in heat input elongation properties increases. As voltage increases heat input increases and thus the elongation increases with voltage and decreases with increase in speed.

The interaction effects of wire feed rate, arc voltage and welding speed are shown in fig. 7.12 and fig 7.13. The fig 7.12 clearly shows that % elongation decreases with speed ,from 17.61 to 15.05 when arc voltage was minimum while it remained almost constant when voltage was maximum. The figure 7.13 depicts that Y.S decreased drastically with speed , from 19.88 to 16.6 , when wire feed rate was minimum however it increased very slightly from 18.24 to 18.99 when wire feed rate was at maximum level.

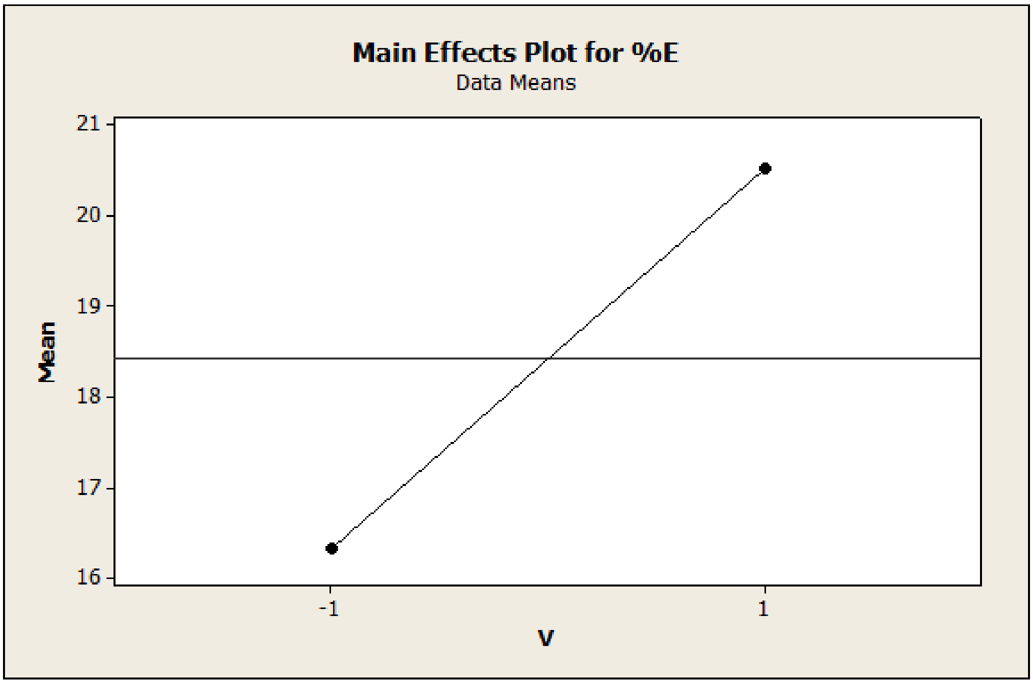


Fig 7.10:-Main effect of arc voltage on %Elongation

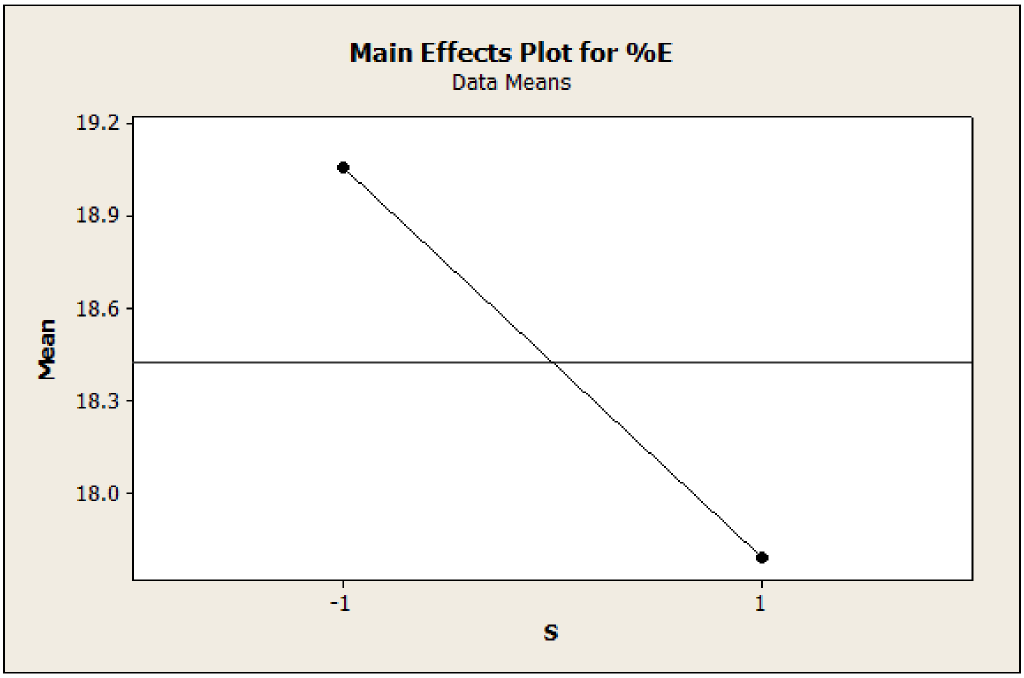


Fig 7.11:-Main effect of welding speed on %Elongation

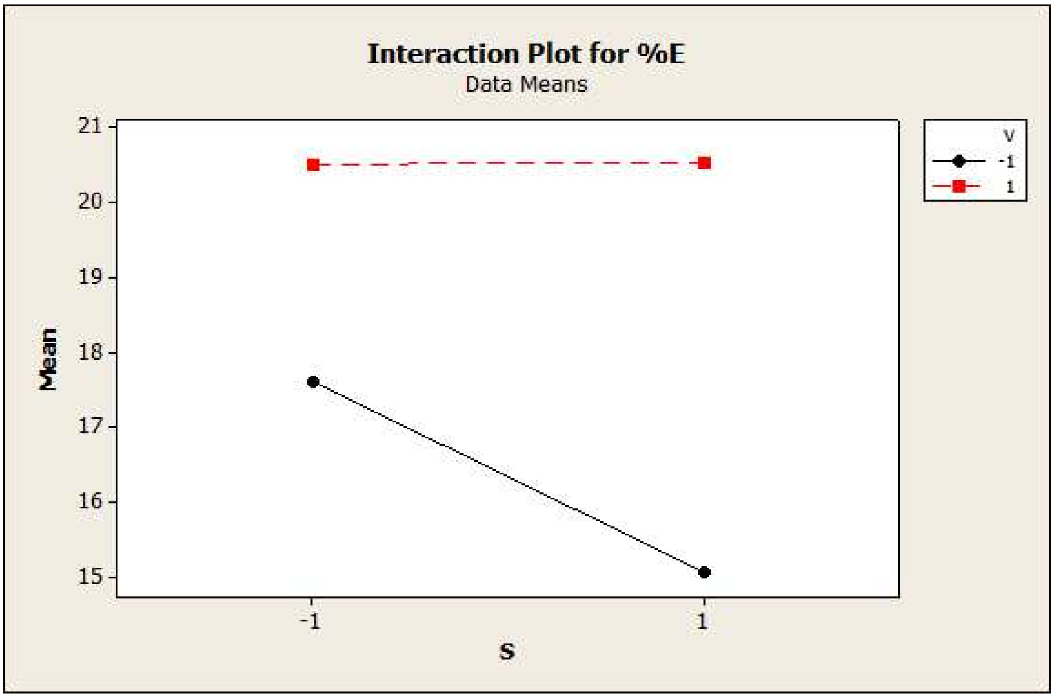


Fig7.12:- Interaction effects of welding speed and arc voltage on % elongation

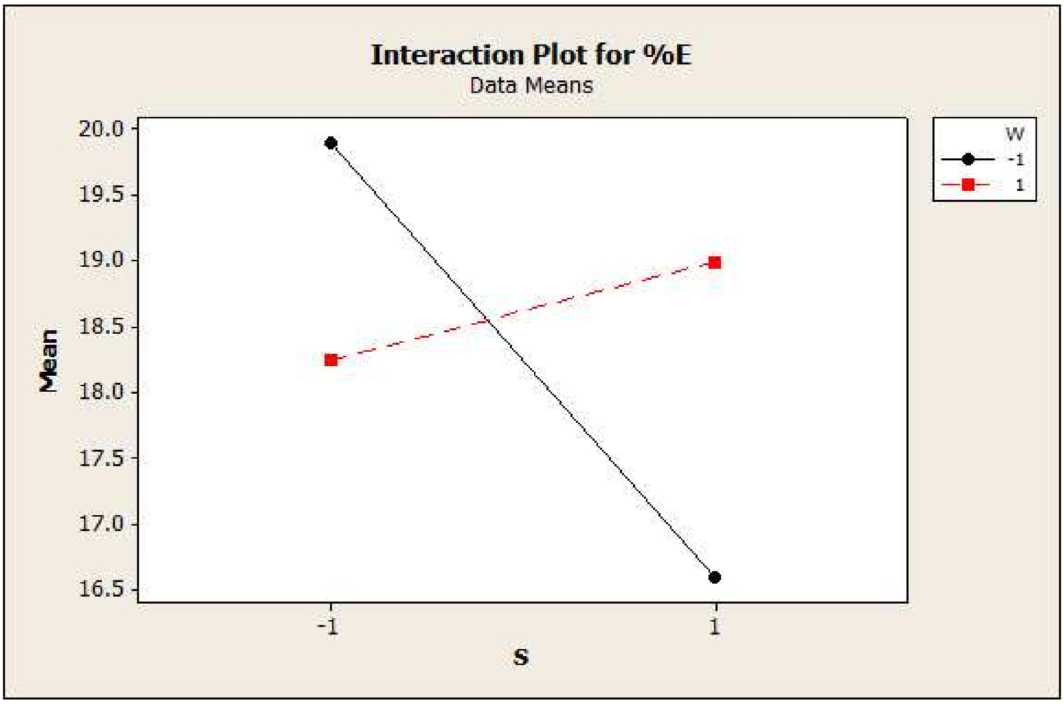


Fig7.13:- Interaction effects of speed and wire feed rate on % elongation

7.4 Main and interaction effects of process parameters on Impact strength

Impact strength decreased from 72.2 joules to 64.06 joules on going from low level to high level of wire feed rate as shown in fig.7.14.Impact strength increases from 67.1J to 69.4J when speed increases from low level to high level as shown in fig 7.15. It decreases from 73.55J to 62.7J as arc voltage increases from low level to high level as shown in fig 7.16. Impact properties decrease with increase in heat input thus when voltage ,wire feed rate(current) increases it decreases however it increases with increase in welding speed as heat input decreases with increase in welding speed.

The interaction effects of wire feed rate, arc voltage and welding speed are shown in fig. 7.17.The two lines for the low level and high level are not parallel which clearly shows that there is interaction effect. Fig7.17 clearly shows that when wire feed rate is at minimum level , impact strength decreases from 73.2J to 71.18J ,with increase in speed. However it increases with speed when wire feed rate is at maximum level.

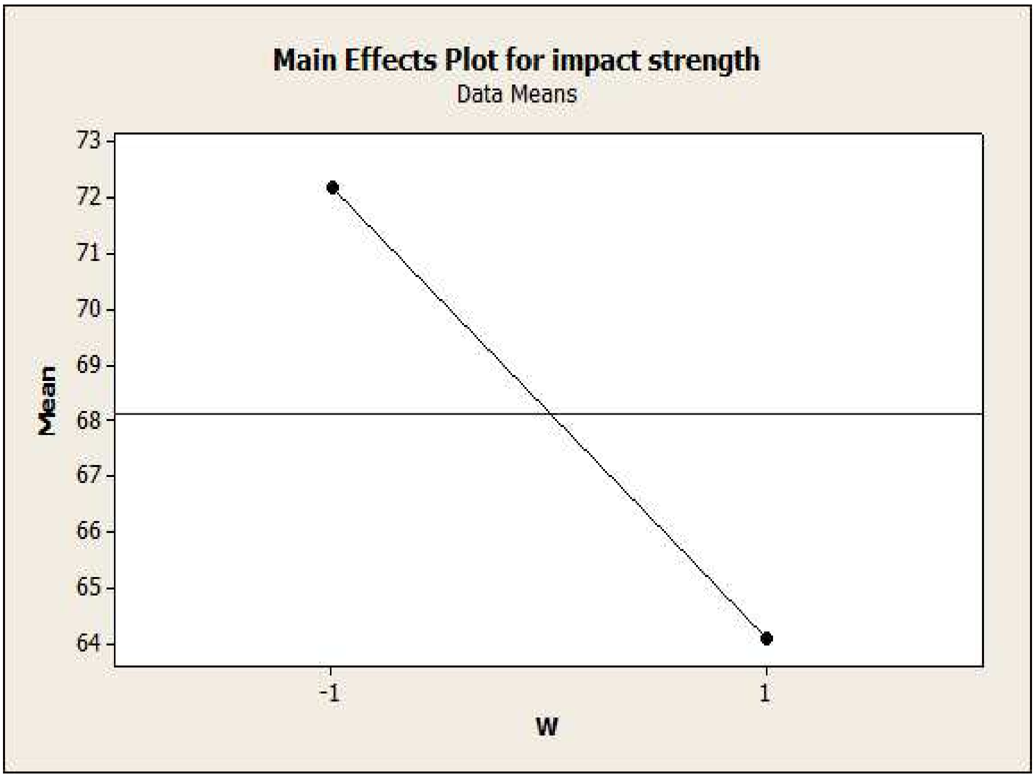


Fig 7.14:- Main effect of wire feed rate on impact strength

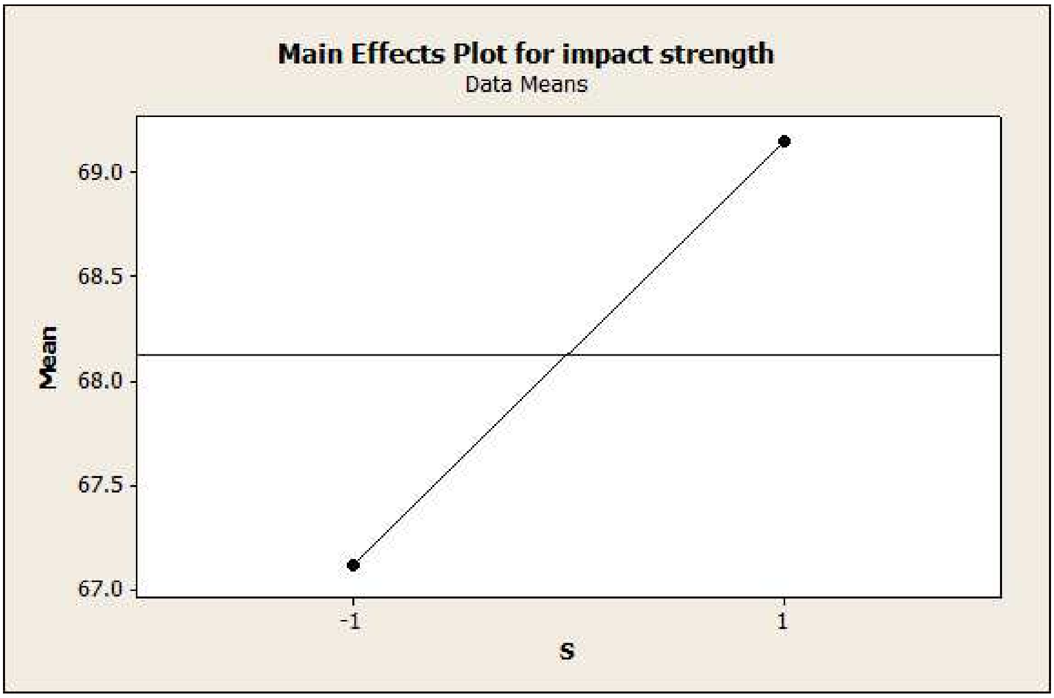


Fig7.15:- Main effect of welding speed on impact strength

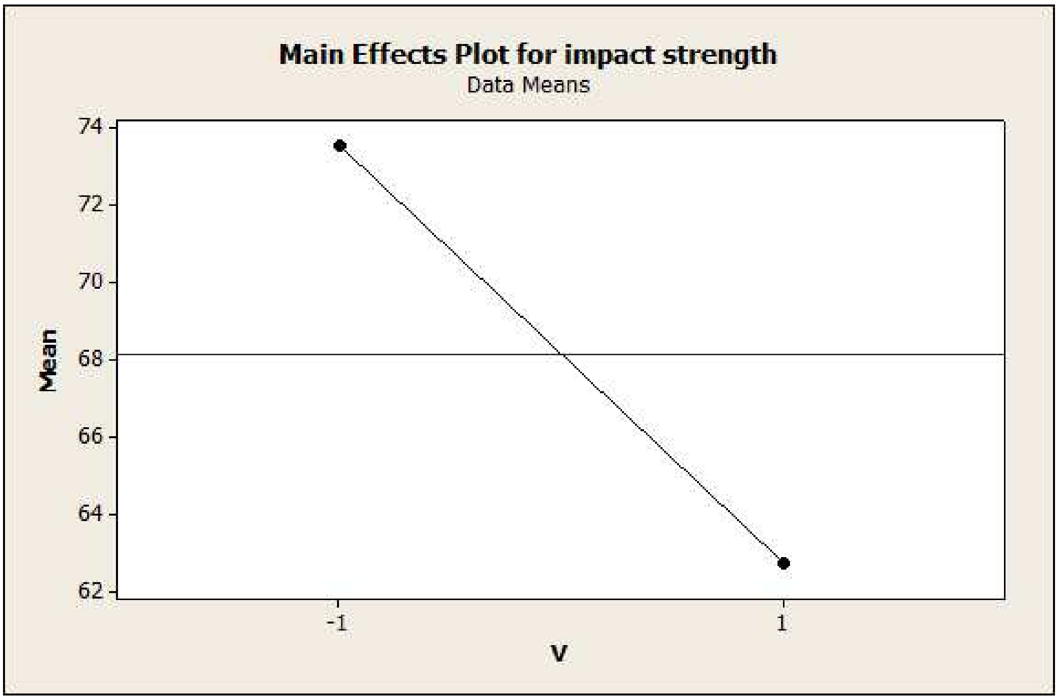


Fig 7.16:-Main effect of arc voltage on impact strength

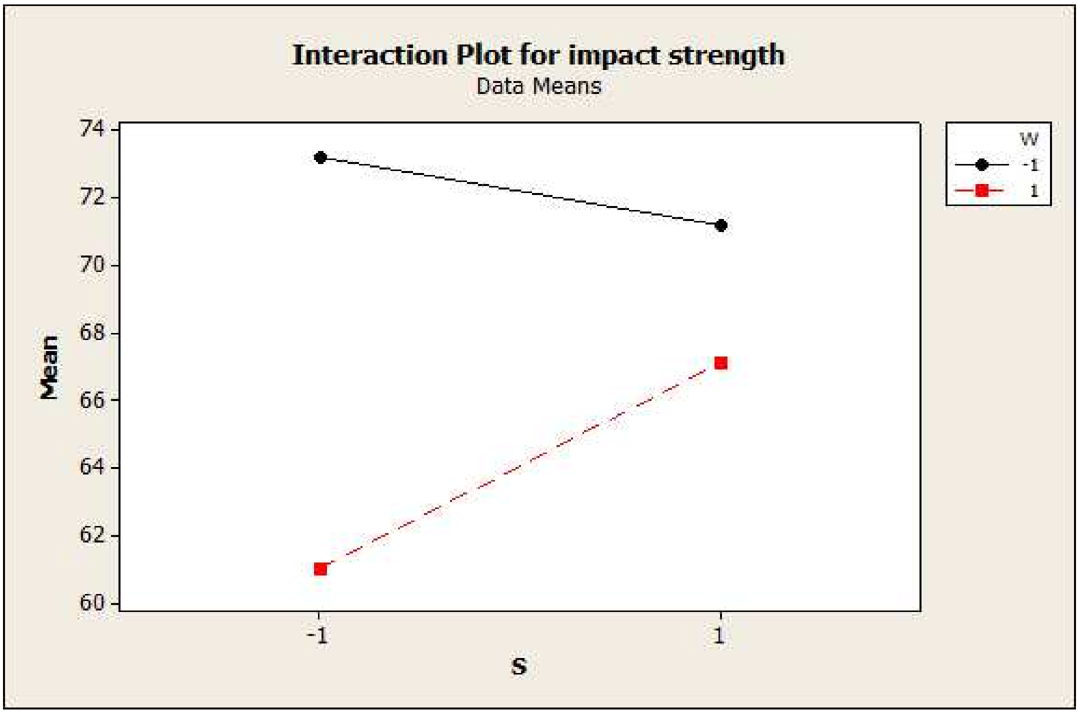


Fig7.17:-Interaction effects of speed and wire feed rate on impact strength

7.5 Main and interaction effects of process parameters on notch tensile strength.

Notch tensile strength (NTS) decreased from 618MPa to 537.5Mpa on going from low level to high level of arc voltage as shown in fig.7.18. NTS increases from 540.5Mpa to 615.44 Mpa when speed increases from low level to high level as shown in fig 7.19. Notch tensile strength follows same trend as UTS . it increases with decrease in heat input so it decreases with increase in voltage and wire feed rate(current) and increases with increase in speed.

The interaction effects of wire feed rate, arc voltage and welding speed are shown in fig. 7.20 and fig 7.21.The two lines for the low level and high level are not parallel which clearly shows that there is interaction effect. Fig7.20 clearly shows that when wire feed rate is minimum NTS increases from 586MPa to 495Mpa with increase in welding speed however at maximum wire feed rate NTS increases from 495MPa to 635MPa. The Fig 7.21 shows that NTS decreases with the wire feed rate, from 656MPa to 580MPa when voltage was at minimum. But it increases with wire feed rate, from 525MPa to 550MPa , when arc voltage is at maximum value.

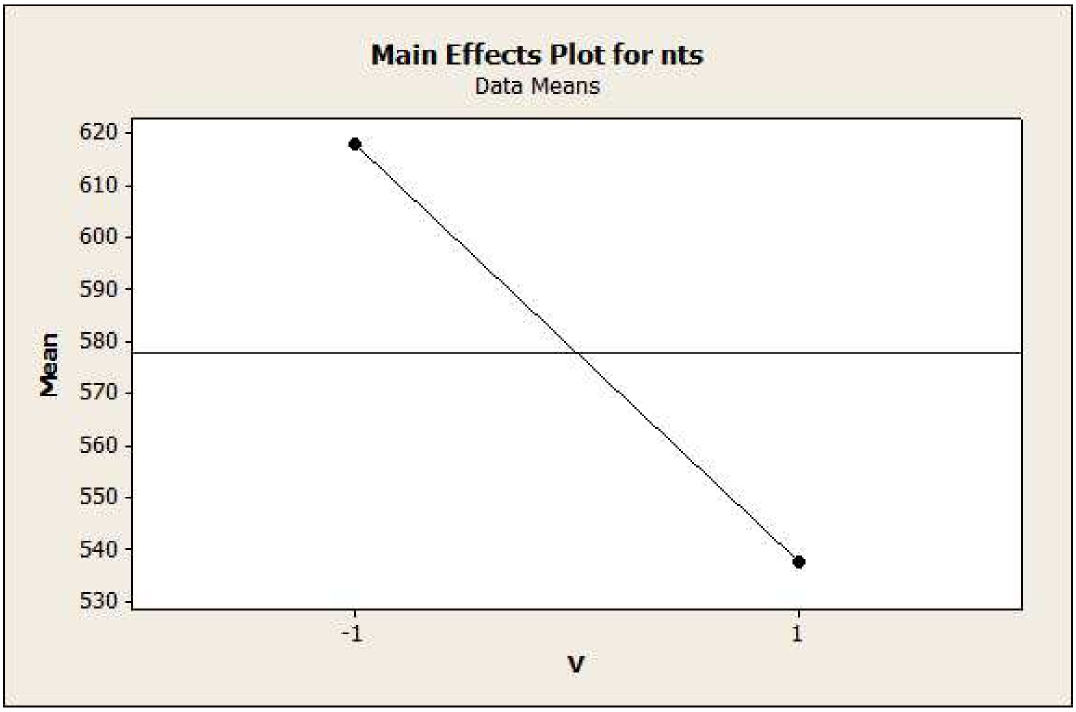


Fig 7.18:-Main effect of arc voltage on N.T.S

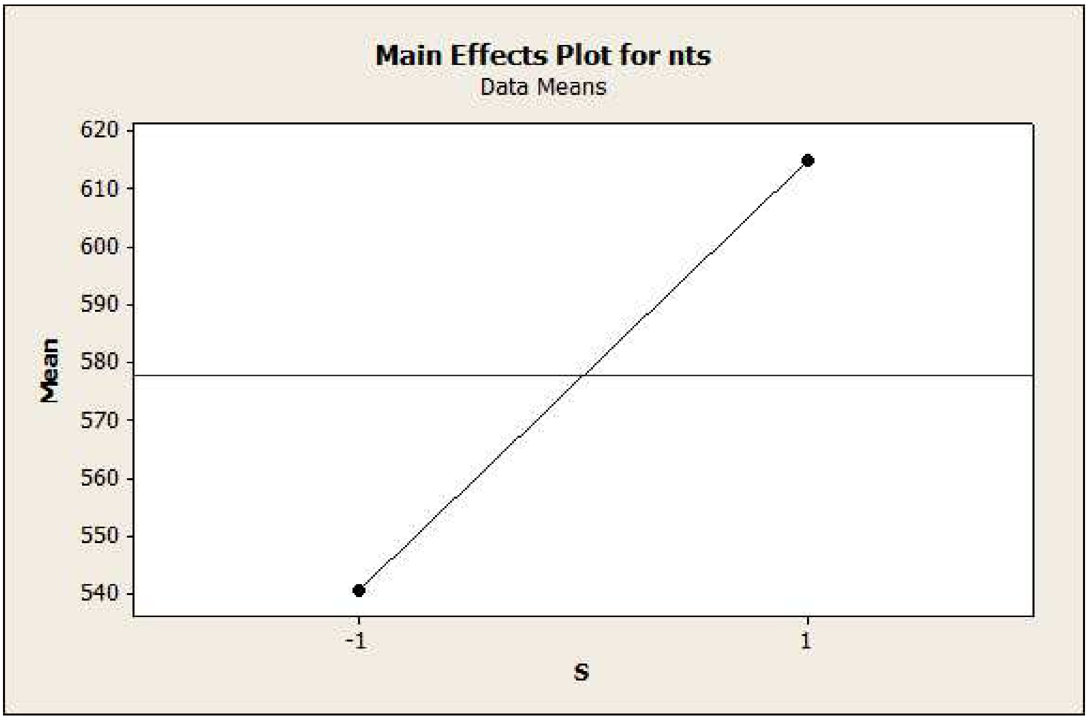


Fig 7.19:-Main effect of welding speed on N.T.S

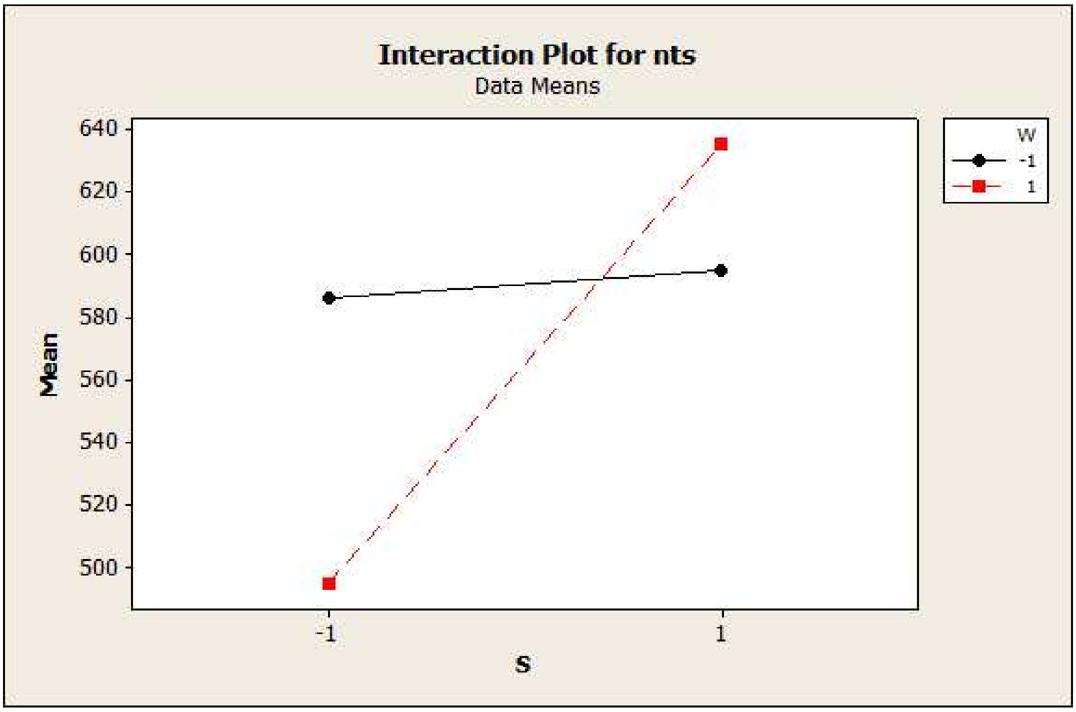


Fig7.20:- interaction effect of wire feed rate and welding speed on N.T.S

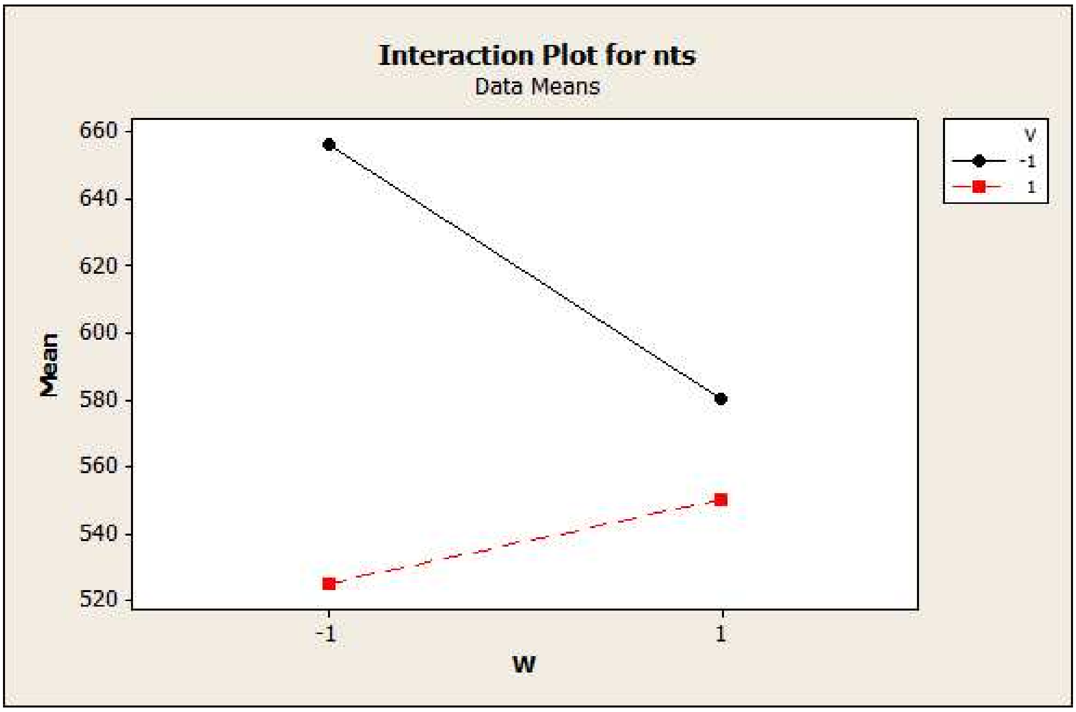


Fig7.21:- interaction effects of wire feed rate and arc voltage on N.T.S

7.6 Scatter Diagram:- The validity of mathematical models developed can be further checked by drawing scatter diagrams. Scatter diagrams for ultimate tensile strength, yield strength, % elongation, impact strength and notch tensile strength were shown in fig 7.22 to fig 7.26 respectively. The observed values and estimated values of the responses are scattered close to 45^0 line indicating an almost perfect fit of the model developed.

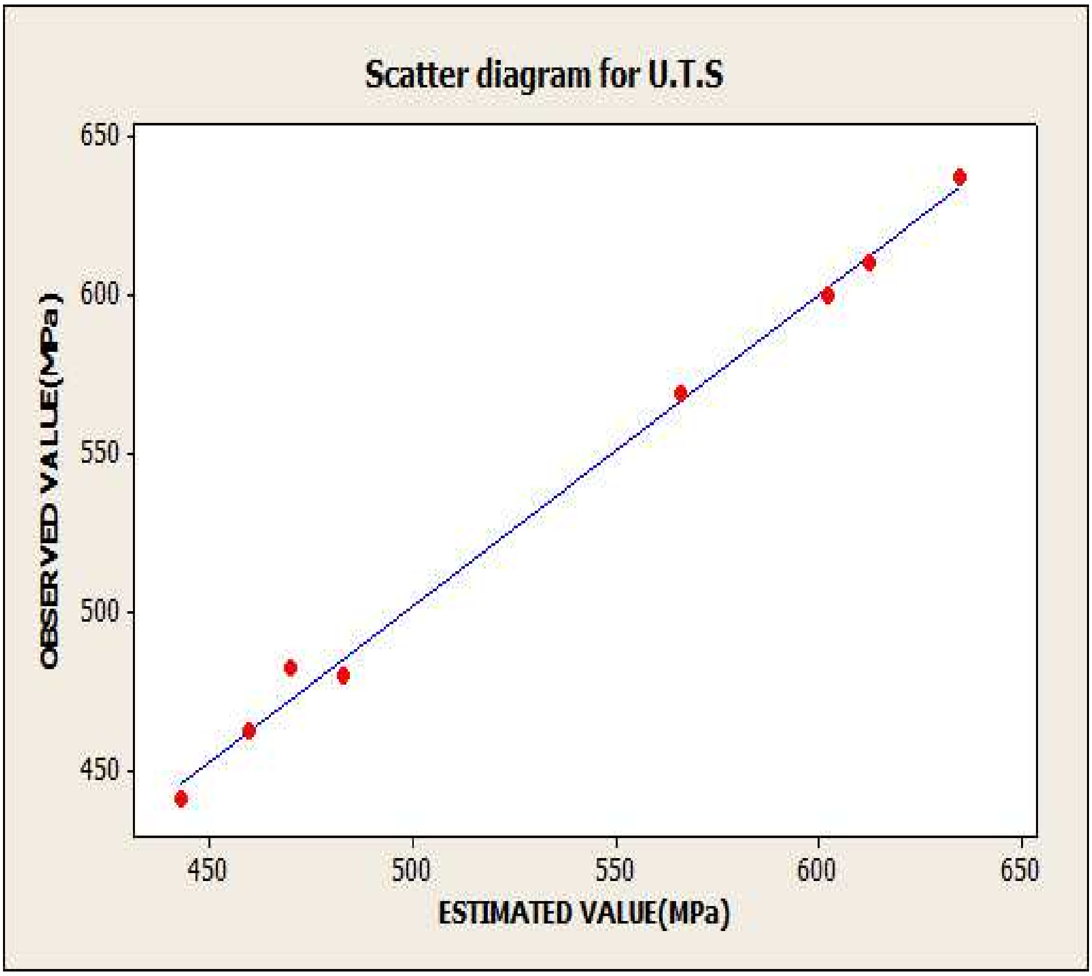


Fig 7.22:- Scatter diagram for U.T.S

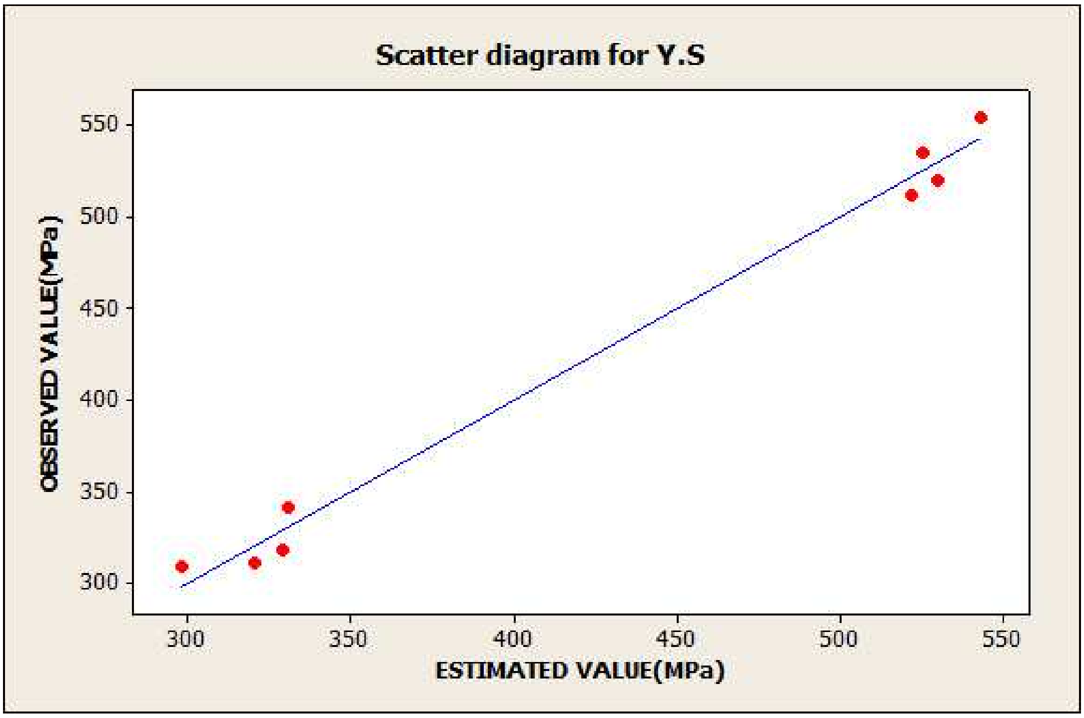


Fig7.23 Scatter diagram for Y.S

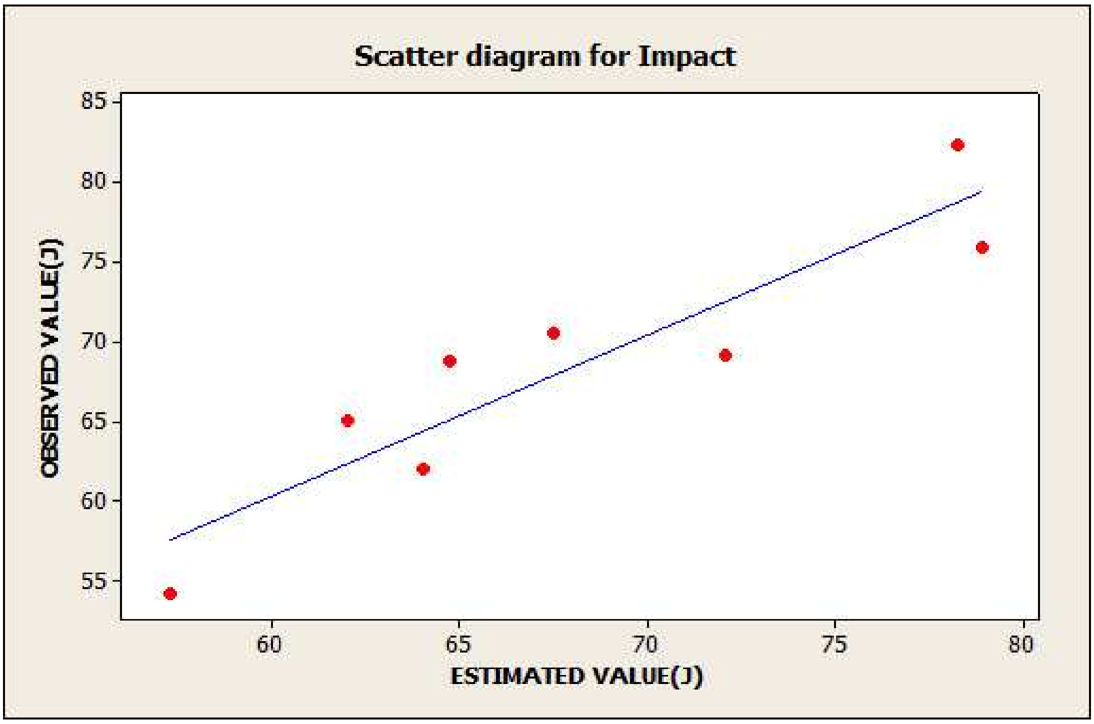


Fig7.24 :-Scatter diagram for impact strength

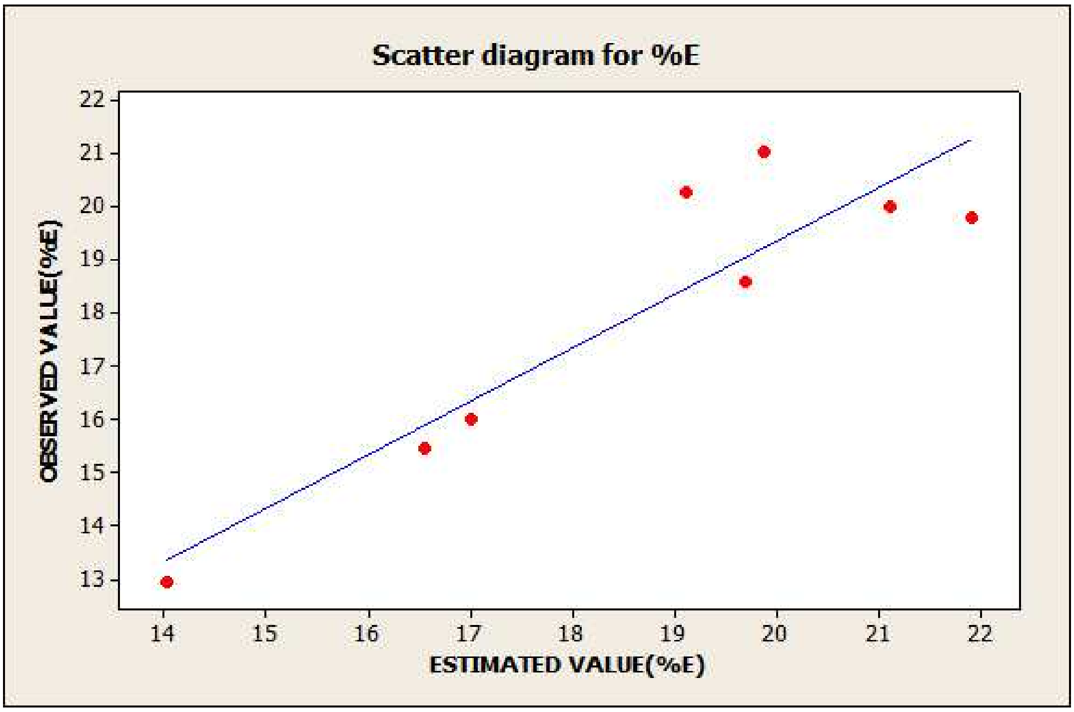


Fig7.25:-Scatter diagram for %Elongation

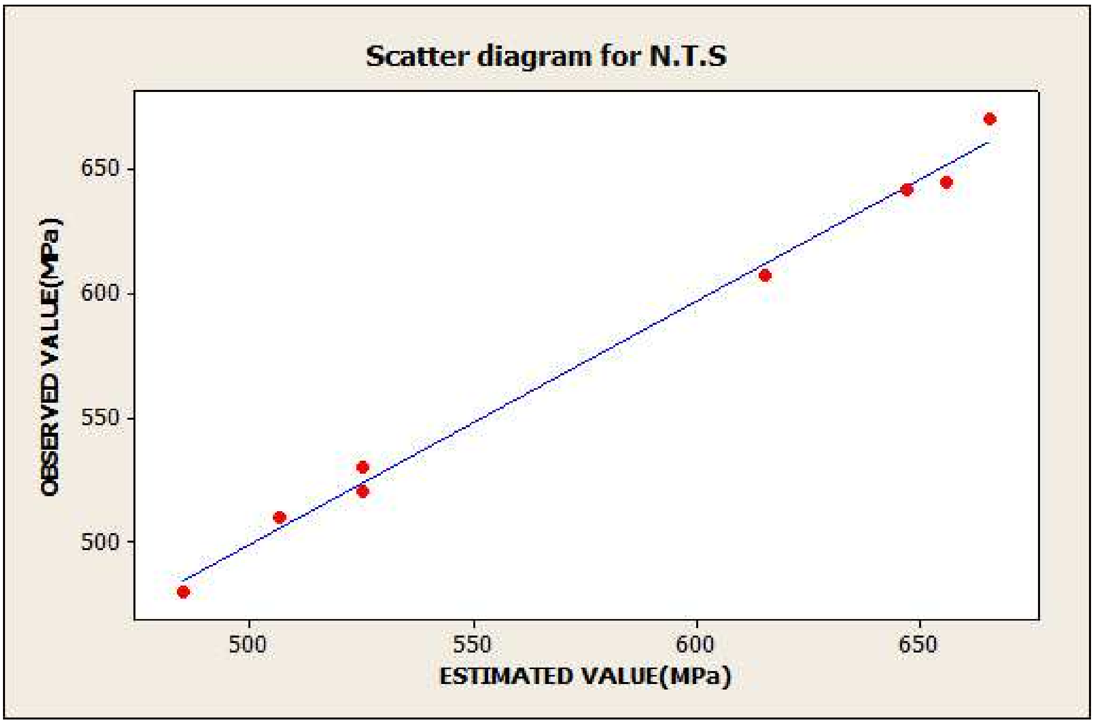


Fig7.26 :- scatter plot for NTS

CHAPTER-8

CONCLUSION & FUTURE SCOPE

8.1 Conclusion

The effects of welding process parameters on mechanical properties using GMAW process have been studied and the following conclusions may be drawn from this analysis:

- Mathematical models have been developed to predict the mechanical behavior of Gas metal arc welded mild steel incorporating main and interaction effects. The developed models can be effectively used to predict the mechanical behaviour within the range of parameters considered.
- Ultimate tensile strength (UTS) decreases with increase in voltage and wire feed rate while it increases with increase in welding speed.
- Yield strength decreases with increase in voltage while it increases with increase in welding speed.
- Elongation increases with increase in wire feed rate while it decreases with increase in speed
- Notch tensile strength increases with increase in welding speed but decreases with increase in arc voltage .
- Impact strength increases with increase in welding speed but decreases with increase in wire feed rate and arc voltage.
- The notch strength of welded specimen was found more than their corresponding ultimate tensile strength i.e notch strength ratio was greater than one depicting that they are insensitive to notch and the specimen are notch ductile. The notch strength ratio of welded metal was always less than the NSR of base metal.
- Interaction effects have considerable influence over the mechanical properties and their effects cannot be neglected.
- All the relationships are linear in nature and can be effectively utilized for optimizing the conditions.

8.2 Scope for future work

In this study, process parameters selected were arc voltage, wire feed rate and welding speed. Effects of process parameters on ultimate tensile strength, notch tensile strength impact strength ,yield strength and % elongation were studied. However for a detailed and indepth reasoning effects of process parameters on micro-hardness and microstructure can be studied. The study can further be carried out by adding process parameters such as nozzle to plate distance, gas flow rate and types of shielding gases used. The study can also be focused on fracture analysis of specimens.

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